SAFETY IMPACT STUDY OF CENTERLINE RUMBLE STRIPS IN GEORGIA

A Thesis
Presented to
The Academic Faculty

By

Jerome Ga Nok Sin

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in the
School of Civil and Environmental Engineering

Georgia Institute of Technology
May 2014

SAFETY IMPACT STUDY OF CENTERLINE RUMBLE STRIPS IN GEORGIA

Approved by:

Dr. Michael P. Hunter, Advisor
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Michael O. Rodgers
School of Civil and Environmental Engineering
Georgia Institute of Technology

Dr. Angshuman Guin
School of Civil and Environmental Engineering
Georgia Institute of Technology

Date Approved: January 10, 2014

For the Lord is good;
His steadfast love endures forever,
and his faithfulness to all generations.

Psalm 100:5

ACKNOWLEDGEMENTS

First, I would like to thank my advisor, Dr. Michael Hunter, who has generously given me the opportunity and support to pursue this research. In addition, I would like to thank those on my thesis committee, Dr. Michael Hunter, Dr. Angshuman Guin, and Dr. Michael Rodgers, for their invaluable expertise, constructive criticism, and guidance over the course of my graduate program and the writing of this thesis. In addition, they have continually challenged me to pursue excellence in all that I do.

I would also like to thank everyone in the lab that has helped me immensely throughout my graduate program, whether it was setting up a printer, choosing courses, working in group projects, or writing my thesis: Popa Pratyaksa, Laura Schmitt, Sam Sim, Laura Stahley, Wonho Suh, and several others. Even though I was not in the lab often, I sincerely appreciated all of their positive encouragements, especially when writing my thesis.

Third, I would especially like to express love and gratitude to my family for their unconditional love, encouragements, and support that helped get me through some of the most trying times. Mom and Dad, thank you for your patience and words of wisdom regarding perseverance and confidence in God no matter the situation. I would also like to thank those at the Journey Church of Atlanta. My brothers and sisters, your irreplaceable friendships, company, prayers, and encouragements have not only made my graduate program memorable, but continually pointed me towards He who is greater.

Ultimately, I would like to give my sincere gratitude and thanks to Jesus Christ, my Lord and Savior, without whom I would not be who I am and where I am today. His unending mercies, abundant blessings, steadfast love, and unchanging faithfulness relentlessly keep me and lead me back to Him, even when my heart is distant, for He is the way, the truth, and the life.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CLRS	Centerline Rumble Strips
CMF	Crash Modification Factor
CO	County
CR	County Route
DOT	Department of Transportation
E	East
FARS	Fatality Analysis Reporting System
FM	From
GIS	Geographical Information System
GDOT	Georgia Department of Transportation
LOC	Locations
mph	Miles per hour
MP	Milepost
RCLINK	Roadway Characteristic Identification Number
SEV	Several
SPF	Safety Performance Function
SR	State Route
STARS	State Traffic and Report Statistics
TransPI	Transportation Project Information
VMT	Vehicle-miles traveled
Vpd	Vehicles per day

SUMMARY

Within the last decade, centerline rumble strips have become increasingly prevalent as a countermeasure to cross-over the centerline crashes on undivided roadways throughout the United States. Within the state of Georgia, nearly 200 miles of centerline rumble strips have been installed in an effort to address the severity and frequency of crashes involving the centerline. With several thousands of miles of new installations throughout the nation in the last decade, much literature on this subject is still being amassed. This study seeks to explore the impacts centerline rumble strips have on physical roadway conditions as well as quantify the impacts centerline rumble strips have on roadway safety.

This thesis begins with a literature review providing a thorough overview of information from around the United States regarding the safety, usage, and impacts of centerline rumble strips. Next, the thesis presents results from a survey sent to state DOTs around the country, focusing on their current stance on centerline rumble strips as well as any potential issues encountered. Third, the thesis examines information regarding centerline rumble strip usage in Georgia by exploring and analyzing rash data from roadways with centerline rumble strips before and after their implementation. Finally, the thesis concludes with a summary of the results, limitations, and a discussion of the potential for future research.

From the survey, the general consensus of responding state DOTs is that they are satisfied with centerline rumble strips and are continuing to construct them. The few that encountered issues such as accelerated pavement deterioration primarily attributed them to poor pavement conditions prior to the installation of centerline rumble strips. In analyzing the crash data two years before and two years after installation, the analyses conducted show that centerline rumble strips may have a slight positive impact on safety. Of the three analyses conducted, the direct before-after analysis showed an 8.80% crash

reduction on roadways with centerline rumble strips; the comparison before-after analysis showed a 5.58% reduction in crashes on two-lane, two-way undivided roadway segments with centerline rumble strips compared to a 0.76% reduction in crashes on other Georgia roadways with the same characteristics; the comparative analysis revealed a crash modification factor (CMF) under 1.0 in the period after installation compared to a CMF of above 1.0 before installation indicating a reduction in crashes which may be attributed to centerline rumble strips.

Though the three analyses suggest positive safety impacts, caution must be exercised as it is possible that the findings are the result of selection bias, regression-to-the-mean, changes in driver behaviors, changes in crash reporting, or other unknown factors unrelated to centerline rumble strips. In addition, concerns regarding the methods in which data was collected prior to this study and the lack of extensive crash data for more than two years before and two years after installation and were limitations in this study. While some concerns may not be mitigated, there is potential for future research, particularly in employing a full empirical Bayes study in order to better understand the safety impacts of centerline rumble strips in Georgia.

CHAPTER 1

INTRODUCTION

Despite decreasing trends nationwide, crashes remain a significant burden to both the United States and its people, costing over $100-billion per year. Therefore, there has been increasing desires across transportation agencies to engineer innovative and inexpensive countermeasures to address any safety issues that may assist in lowering crash rates. In the United States, though 40% of crashes occur on rural roadways, 60% of all fatalities occur on such highways [21, 40]. Of particular concern are crashes that involve crossing over the centerline onto oncoming traffic, also known as cross-over crashes. The severity of crashes where the vehicle shifts onto the opposing lane is often higher than other crash types and is compounded because of the additive nature of the vehicle speeds at the time of collision [43]. Though crashes are often accidents, many are preventable, motivating officials and engineers to design countermeasures that mitigate cross-over crashes on two-way highways. One such countermeasure that has become increasingly prevalent in the past decade is characterized by a series of grooved indentations or devices placed along the centerline, known as centerline rumble strips.

1.1 Background

First proposed nearly two decades ago, centerline rumble strips has been widely implemented in the past decade from experimental sections of up to 15 miles each in 2000 to well over 11,000 miles by 2010. Through auditory and visual stimuli, centerline rumble strips work similarly to shoulder rumble strips, by alerting motorists that they are inadvertently crossing the centerline [21, 40]. As centerline rumble strips have been in use for over a decade, various studies have been conducted regarding the safety effectiveness of this countermeasure. However, just as driving behavior and crash patterns differ from region to region within the United States, safety effectiveness results obtained in one region are not necessarily representative of the safety effectiveness in another region. Because the majority of safety studies conducted represents states in the Northeast or Midwest, this thesis seeks to determine the safety effectiveness of centerline rumble strips in the context of Georgia and the Southeast.

In the state of Georgia, the Georgia Department of Transportation (GDOT) has implemented centerline rumble strips on a variety of roadways in rural areas, with nearly 200 miles installed between 2005 and 2006. Citing significant crash reductions in other states, GDOT embarked on a demonstration program in Georgia where centerline rumble strips were implemented either as a stand-alone project or a part of existing resurfacing project, with costs expected to average $6,000 per centerline mile or $2,000 per centerline mile, respectively. The majority of these installations were completed as a part of GDOT's Safety Action Plan, which was developed in order to address the challenges associated with increasing traffic volumes, an aging population, aggressive driving, and driver attentiveness within the state. By implementing engineering related safety efforts, GDOT hopes to achieve its internal goal of reducing the total number of crashes by 2% annually as well as meet AASHTO's goal of a fatality rate of 1.0 per 100 million vehicle-miles-traveled [43].

1.2 Project Goals

The results of this study are presented through three analyses and a comprehensive survey. The first analysis conducted is a direct before-after analysis, also known as a naïve before-after analysis, in which the number of crashes before centerline rumble strips installation is directly compared to the number of crashes after centerline rumble strips installation. While this analysis may reveal a promising level of safety effectiveness, it does not account for the changes in crashes due to factors other than centerline rumble strips. The second analysis conducted is comparison before-after analysis, which compares the before and after reduction in crashes on roadways with centerline rumble strips to roadways without centerline rumble strips. The third analysis is simple empirical Bayes analysis, which compares the crashes per vehicle-miles-traveled of roadways with centerline rumble strips to that of roadways without centerline rumble strips. Both the comparison before-after analysis and simple empirical Bayes analysis utilize a reference standard for comparison, which consists of roadways with similar characteristics to those with centerline rumble strips. In this study, these roadways are primarily rural, two-way, two-lane state highways throughout Georgia. While this study does not claim that all crash reductions can be attributed to centerline rumble strips, it lays the foundation for a future, more in-depth analysis that accounts for a multitude of other factors that may impact the rate of crashes on these roadways.

In addition to evaluating the safety effectiveness of centerline rumble strips, this study seeks to investigate centerline rumble strips as a countermeasure. This is accomplished in two ways: a literature review that investigates information regarding centerline rumble strips as a countermeasure and any studies conducted on the subject, and a survey that seeks for the motivation behind centerline rumble strips installation and whether or not there are adverse effects associated with centerline rumble strips. Through the examination of studies conducted the past two decades, the literature review investigates the history behind, the nature of, and the safety effects of centerline rumble strips. In addition, the literature review will explore several types of safety analyses that have been conducted on centerline rumble strips. Secondly, the survey will investigate why other state transportation agencies installed centerline rumble strips, whether they have experienced adverse effects, and what they did to mitigate such effects; in the state of Georgia, GDOT has not been actively pursuing centerline rumble strips installations since 2006 citing pavement deterioration. Through this comprehensive survey, centerline rumble strips usage throughout the United States will be determined, and information regarding the state-of-the-art practice of centerline rumble strips will be acquired.

1.3 Thesis Organization

This thesis is organized in the following manner. Chapter 2 presents a basic overview of the background, properties, applications, benefits, and concerns of centerline rumble strips as well as a review of different types of safety analyses conducted in the past. Chapter 3 highlights key results of the survey. Chapter 4 describes the methodology behind this study, which focuses on determining the safety effectiveness of centerline rumble strips in Georgia through evaluating the numbers and rates of crashes before and after their construction. Chapter 5 presents the results of the analyses performed in Chapter 4. This chapter also includes a discussion of the impact of the results on the current centerline rumble strips installed and potential application of this countermeasure in Georgia. Lastly, Chapter 6 concludes the study with a summary of the results, limitations, and the potential for future research.

CHAPTER 2

LITERATURE REVIEW

This literature review aims at reporting the current practice of centerline rumble strips in the United States with a particular emphasis on the Southeast region of the country. Centerline rumble strips have been shown over and over again to have significant effects on decreasing crashes and currently serves as an effective countermeasure to lane departure related crashes [36]. Furthermore, this review presents the conclusions of several safety benefit evaluation studies for centerline rumble strips in general. Lastly, several types of studies are examined in order to serve as a primer to the analyses of this study.

2.1 Background of Centerline Rumble Strips

The first rumble strips were introduced as shoulder rumble strips in 1955 on the Jersey Turnpike of New Jersey and soon after began appearing in many states beginning in the 1960s [5]. Due to their prominence, most drivers are familiar with shoulder rumble strips and their presence on the shoulders of freeways and principle arterials. Due to their familiarity and effectiveness, shoulder rumble strips have been proven to alert drivers that depart the roadway due to drowsiness, fatigue, or inattentiveness. When a vehicle passes over the rumble strips, a combination of auditory and tactile stimuli alerts the motorist to change their maneuver in order to avoid a potential crash situation [36].

Currently, the most common method of keeping drivers in their designated lanes is through the painting of road markings. However, its effectiveness is limited to the attentiveness of drivers and good environmental conditions [39]. As rural two-lane roads lack physical measures such as wide medians or barriers that separate opposing traffic, failure of keeping in the proper lane, crossing the centerline, and sideswiping a vehicle traveling the opposite direction or striking a vehicle head-on is a major crash risk.

Several factors lead to this risk: poor environmental conditions, driver inattention, driver fatigue, or traveling at speeds not intended for the roadway. Though these factors can be partially mitigated by engineering improvements such as roadway widening or the installation of a median barrier, such improvements are often costly [36]. With centerline rumble strips, the same concept behind shoulder rumble strips is applied: whether there are raised bumps or grooved indentations in the roadway, the striking of a vehicle's tires with these surfaces produces noise that provides the driver with an auditory and tactile warning of leaving the travel lane. The primary difference between centerline rumble strips and shoulder rumble strips is dependent on their placement and target crash types: to warn inattentive, distracted, or fatigued drivers that their vehicles are encroaching on the centerlines of two-way, undivided roadways and avoid head-on and opposite-direction sideswipe crashes. These crashes include any crash that began with the vehicle encroaching on the centerline, but exclude crashes that began by running off the road to the right and overcorrecting to the left past the centerline, and any crash that began with a vehicle's loss of control due to water, ice, or snow prior to crossing the centerline [39].

Use of centerline rumble strips has been increasing since the 1990s. Early surveys in 2000 indicated that 20 states and at least one Canadian province had experimented or implemented centerline rumble strips ranging from a few miles up to 15 miles [39]. By 2003, many rumble strips installation were installed on an experimental basis [36]. Examples of these installations included:

- A 2.9-miles section of centerline rumble strips installed in 1994 in Delaware [6]
- A 17-miles section of centerline rumble strips installed along a winding two-lane mountain highway in 1996 in Colorado [34]
- 100-miles of centerline rumble strips installed statewide in Washington [33]

Many of these centerline rumble strips were implemented as a response to the serious problem of roadway departure fatalities. As few studies existed on the effectiveness and safety impact of centerline rumble strips at the time, several transportation agencies opted to evaluate the effectiveness of centerline rumble strips relevant to their geographic location and conditions. Today, many states are still performing studies on the effectiveness of centerline rumble strips, and as of 2011, there have been over 11,300 miles installed around the country [21].

2.2 Crash Statistics

> "Crashes that qualify as centerline rumble strips correctable are any cross-centerline (cross-over) crash that begins with a vehicle encroaching on the opposing lane, excluding any crash that began by running off the road to the right and overcorrecting and any crash that began by a vehicle going out of control owing to water, ice snow, etc., before crossing the centerline." [39]

2.2.1 Roadway Environment

In comparing urban roadways to rural roadways, though urban roadways experience a higher rate of motor vehicle crashes, fatal crashes are more likely to occur in rural areas [36]. While rural roads account for 40% of all vehicular travel, they account for 60% of all fatalities [39]. These statistics have not changed much over time. A 2001 report found that 60% of fatal crashes occurred on rural roads; a 2009 study found that 56% of fatal crashes occurred on rural roads. Furthermore, the fatality rate per 100 million vehicle-miles-traveled was 2.7 times higher in rural areas than in urban areas. These nationwide statistics were echoed by Georgia and other southeastern states, as detailed in Table 1 [49, 50].

Table 1: Rural Versus Urban Fatalities in the Southeast [49]

State	Rural Fatalities		Urban Fatalities	
	Number	Percent	Number	Percent
Alabama	496	58	281	33
Georgia	**659**	**51**	**625**	**49**
Mississippi	507	72	193	28
Tennessee	577	58	412	42

Data also reveals that 74% of the fatal crashes on rural roads were on two-lane roads; 20% of these involved two vehicles travelling in opposite directions [21]. Lastly, a total of 83% of two-lane undivided road crashes occurred on rural roads [30]. In comparison to urban roads, rural roads possess unique characteristics, generally including higher traffic speeds, lower rates of seatbelt use, and longer emergency response times [36].

2.2.2 Roadway Geometry

In comparing crash rates of tangent sections to horizontal curve sections, tangent sections experience around 65% of all fatal crashes, while horizontal curve sections experience around 35% of all fatal crashes. However, though there may be more incidents on tangent sections, this characteristic has not been determined to be a statistically significant variable in the context of centerline rumble strips and the type of crashes it addresses. Rather, head-on crashes and opposite-direction sideswipe crashes experienced a reduction of 47% on tangent sections and 49% on horizontal curve sections, concluding that the safety effectiveness of centerline rumble strips is the same for both roadway geometry types [53].

2.2.3 Crash Type

Aside from the characteristics of roadways, numerous studies discuss the type of crashes addressed with centerline rumble strips, focusing specifically on cross-over crashes in the form of head-on crashes and opposite-direction sideswipe crashes. Data from the 1999 Fatality Analysis Reporting System (FARS) revealed that 18% of non-intersection fatal crashes were a result of two vehicles colliding head-on [30]. This was the same for 1997 and 1998 data and remained consistent throughout the 2000s; the rate was 20% in 2009 [21]. In terms of roadway environment, 75% of head-on crashes occurred on rural roads. Though the high percentage of head-on crashes on undivided, two-lane, two-way roads may suggest failed passing maneuvers, the majority of fatal head-on crashes occurred in non-passing zones [30]. In accounting for other cross-over crashes, opposite-direction sideswipe crashes accounted for approximately 27% of fatal crashes on rural, two-way, two-lane roads [45].

2.2.4 Crash Locations

Strictly studying which side of the road vehicles tend to travel when inadvertently leaving the travel lane is of interest. In a study conducted in Michigan, 47% of crash vehicles departed the travel lane to the left, while 53% departed the roadway to the right [29]. In another study conducted in Texas, 47.3% of all crashes on two-way, two-lane roads involved crossing the centerline, with 41.5% of all crashes on these roads running off the road to the far left side [27].

2.2.5 Causal Factors

A number of factors can cause motorists to leave the travel lane and cross the centerline or run off the road. Of inadvertent causal factors, motorist inattention was the most common. Studies cite that up to 86% of fatal head-on crashes on two-lane highways were a result of the driver being inattentive or asleep [11]. In a 2006 study undertaken by the state of Kentucky, driver inattention was the most frequently cited factor, contributing to over 41% of all crashes [23]. Other causes, such as falling asleep and fatigue, accounted for 5% of all crashes. Another study from Texas confirmed driver inattention as the most frequently cited factor to run-off-the-road crashes, at 24.1%. The second most common cause was falling asleep or driver fatigue, at 12.4%. In cases of driver inattention, common distractions cited included reaching for a cell phone or adjusting the audio system. Ultimately, most crashes have multiple contributing factors [27].

2.3 Properties of Centerline Rumble Strips

Though the design of centerline rumble strips is relatively similar throughout the nation, placement and construction techniques vary widely from agency to agency [23]. As of 2005, no standard definition or policy regarding the form, dimensions, and placement existed [39].

2.3.1 Forms of Rumble Strips

The primary responsibility of rumble strips as a countermeasure can be accomplished with a variety of forms. Rumble strips are primarily installed in four different places along the roadway; from most prevalent to least prevalent, these applications include the shoulder, the centerline, across the roadway (transverse), and down the middle of the travel lane (midline) [21]. Transverse rumble strips incorporate rumbles that are placed across the full width of the travel lanes. These are typically designed to alert motorists of approaching changes in the roadway, such as roundabouts, intersections, and toll plazas [53]. Midline rumble strips, still in the theoretical stage, targets both cross-over and run-off-the-road crashes, mitigating travel lane departures by placing rumbles along the center of the travel lane [21, 28]. As of 2011, no transportation agencies have installed this form, potentially due to negative reactions by motorcyclists and bicyclists. In addition to being a major nuisance, some riders thought it would be dangerous, as most riders would frequently cross the center of the travel lanes in normal travel [28]. This sentiment does occur due to centerline rumble strips as well, and is explained later in this literature review.

The actual rumble strips themselves predominantly come in four types: raised, milled-in, rolled, and formed; these are illustrated in that order by Figure 1 [38]. By far the most common form of centerline rumble strips is the milled-in rumble strips [39].

Figure 1: Four Forms of Centerline Rumble Strips; from left to right: Raised, Milled-In, Rolled, Formed [37]

Milled-in Rumble Strips

Milled-in rumble strips, also known as ground-in rumble strips, are cut into the road surface by a machine with a cutting head [7]. These grinding machines can grind up to 1.25 miles per hour, and carves out regular indentations on roadway independent of the roadway age [34]. The repetitive milling of the roadway creates smooth, uniform, and consistent grooves in the pavement surface in one of two shapes: football shaped or rectangular shaped (Figure 2). In terms of safety benefits, no statistical differences between the two shapes have been found [42].

Figure 2: Patterns of Milled-in Centerline Rumble Strips, from left to right: Football-shaped, Rectangular-shaped [42]

Due to the nature of the installation, milled-in rumble strips can be installed on new or existing asphalt and Portland cement concrete surfaces. Though they are cut into the pavement, neither type of milled-in rumble strips have not been reported to negatively impact the structure of the roadway, though there are concerns. However, some disadvantages are that milled-in rumble strips tend to be more expensive to implement than other types, are non-reflective in nature, and when driven over, tend to produce greater levels of noise [7, 42].

<u>Formed Rumble Strips or Rolled Rumble Strips</u>

Formed rumble strips consist of V-shaped or rounded grooves pressed into concrete as they are being constructed during the compaction phase of road construction or reconstruction. Similarly, rolled rumble strips consist of rounded grooves pressed into hot asphalt by a roller with a steel pipe welded to the drum, making depressions as it passes over the asphalt [38]. While it produces less noise and is more inexpensive than other types of rumble strip types, formed and rolled rumble strips can only be done during construction or reconstruction, which hinders application [7].

<u>Raised Rumble Strips</u>

Raised rumble strips are raised, narrow, and rounded or rectangular markers that are attached to new or existing pavements. As these rumble strips are affixed to the roadway surface, raised rumble strips can come in several materials, including asphalt, rubber-like material, and plastic. Some advantages include improved retro-reflectivity, as materials such as glass beads can be embedded in the composition to enable greater visibility at night for drivers. In addition, raised rumble strips can be applied to the roadway at any time. However, there have been concerns of raised rumble strips, particularly in areas with wintry weather as snowplows may inadvertently remove them. Furthermore, raised rumble strips tend to be more costly than other types of rumble strips [7].

2.3.2 Application of Centerline Rumble Strips

The applications and physical properties of centerline rumble strips range widely from one jurisdiction to the next. This section touches upon the dimensions, placement, and design considerations of various types of centerline rumble strips.

2.3.2.1 Installation Properties

Typical Dimensions

As dimensions are not standardized, state transportation agencies have developed policies regarding dimensions. Some typical dimensions of this type, expressed in length (dimension perpendicular to the centerline), width (dimension parallel to the centerline), and spacing (space between the center of an indentation to the next) are listed in Table 2.

Table 2: Common Milled-in Centerline Rumble Strips Dimensions [21]

Dimension	Range (inches)		Most Common (inches)
Length	6	25	16
Width	5	9	7
Depth	0.375	0.625	0.5
Spacing	5	48	12

Lateral Placement

Though centerline rumble strips are always installed at the centerline, the actual installation locations may vary. While predominantly installed within the pavement markings that constitute the centerline, centerline rumble strips can be placed in a variety of places around the centerline [21, 53]. Some example placements are illustrated in Figure 3.

Figure 3: Examples of Different Lateral Placements of Centerline Rumble Strips; from left to right: Within Pavement Markings, Extended into Travel Lane, on Either Side of Pavement Markings [53]

Facility Type

The types of roadway centerline rumble strips are installed on vary from agency to agency. These facility types include: urban multi-lane undivided highways, urban two-lane roads, rural multi-lane undivided highways, and rural two-lane roads; most state transportation agencies install on rural two-lane roads. Agencies may or may not have a lane width requirement [53]. For installations where there are more than two lanes, some agencies widen the centerline rumble strip length [2]. In terms of pavement type, the majority of agencies had only installed centerline rumble strips on asphalt; other agencies have installed on both asphalt and concrete [21].

Dual Application

In terms of application with respect to other types of rumble strips, the majority of states with centerline rumble strips had both centerline rumble strips and shoulder rumble strips installed on the same stretch of roadway, while a handful of states had both centerline rumble strips and edge line rumble strips on the same roadway. Furthermore, three states had both centerline rumble strips and edge line rumble strips in sections of roadway with a narrow shoulder of less than three feet or no shoulder [21]. All in all, the decision to install multiple applications of rumble strips on the same stretch of roadway was up to the agency, with some agencies reporting that existing shoulder rumble strips does not influence the site selection process for centerline rumble strips [2].

2.3.2.2 Design Policies and Considerations

As of 2011, nearly two-third of states with centerline rumble strips have some sort of written policies or guidelines for centerline rumble strips installation; the depth of the guidelines varies from state to state. Two-thirds of states with policies had a lane width requirement for installation; one-third of the states with policies had a minimum shoulder width requirement, and roughly half of states with policies had other requirements such as minimum crash rates, AADT, or speed limits for installation [21]. For example, California requires the occurrence of fatal crashes to justify centerline rumble strips installation, while Washington State gives investment priority to locations with AADT of < 8,000, combined lane and shoulder width of 12 to 17 feet, and posted speeds between 45 and 55 mph [23, 33].

Design considerations for centerline rumble strips installation also vary. Some examples regarding design considerations include installations in passing zones, horizontal curves, and places with existing rumble strips. In a 2011 survey, about one-fifth of state transportation agencies with centerline rumble strips intentionally installed them at specific locations such as at curves and no passing zones [21]. Other agencies recommended changes in centerline rumble strips' depth depending on the location, such as shallower milled-in cuts on curves in the instance that motorcycles pass over them [10].

2.4 Benefits of Centerline Rumble Strips

The literature indicates that centerline rumble strips are a low-cost and effective countermeasure for mitigating cross-over crashes [39]. The effectiveness is accomplished and exemplified in several ways and is discussed in this section.

2.4.1 Noise

The noise produced by centerline rumble strips is an auditory stimulus for the motorist. In a study conducted regarding the human perception of changes in sound level, it was concluded that sounds must rise at least 10 dB above the sound of the environment for the user to become alerted to the presence of that sound [26]. As the noise within a car driving on rumble strips is at least 15 dB higher than the normal ambient noise when driving, rumbles strips are effective at alerting the motorist. In addition, there is a positive correlation between rumble strip depth and sound levels, and between speed and sound levels, as seen in Figure 4 [10].

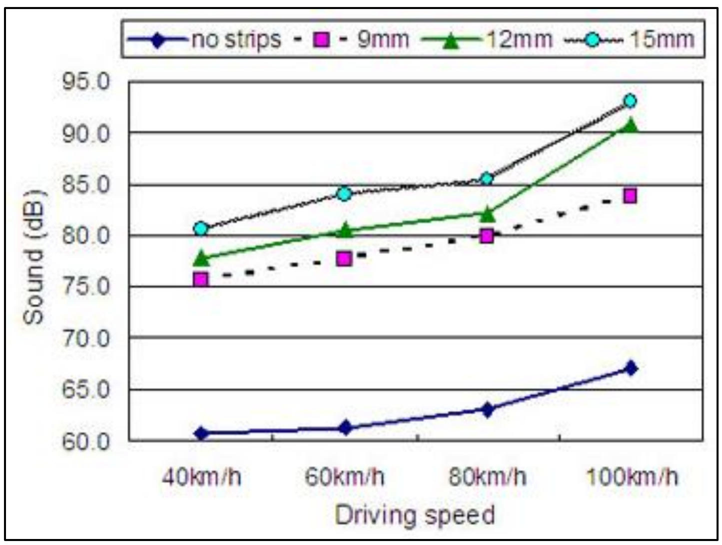


Figure 4: Average Sound Heard by Motorists Driving on Rumble Strips at Various Speeds [10]

In terms of rumble strips placement, a study conducted in Kansas revealed that continuous rumble strips with a spacing of 12-inches produced the highest average decibel levels, followed by the alternating 12-inches and 24-inches spacing; the continuous 24-inches spacing pattern produced the lowest average decibel levels. These results were consistent across different vehicles types and sizes. Thus, additional relationships are hypothesized, including a positive correlation between densities of rumble strips indentations and average decibel levels [41].

2.4.2 Vibration

The secondary purpose of centerline rumble strips is to provide tactile stimulus to the motorist. From a study in Japan, researchers discovered that the vibration in a car driving on rumble strips tend to be at least 10 dB higher than driving on the regular road. In addition, they discovered that there is a positive correlation between the rumble strip depth and the vibration level; these findings are shown in Figure 5 [10].

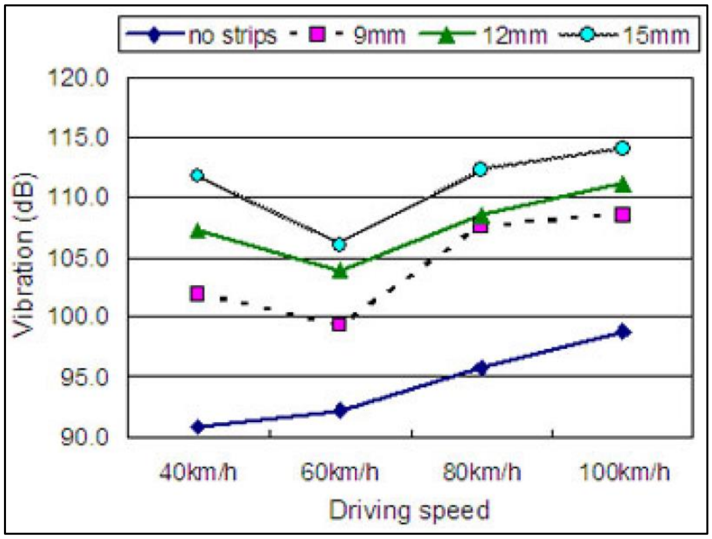


Figure 5: Average Vibration Experienced by Motorists Driving on Rumble Strips at Various Speeds [10]

As of 2009, however, there has yet to be research in determining the minimum level of vibration stimuli required to alert the motorist [53].

2.4.3 Additional Benefits

Centerline rumble strips have multiple other benefits, including improved safety in low visibility driving conditions. A public opinion survey produced an overwhelming response that centerline rumble strips aid in poor visibility conditions, particularly for large truck drivers [37]. Similarly, centerline rumble strips were appreciated by drivers in areas with wintry weather [5, 17]. In Alaska and Minnesota, centerline rumble have made motorists aware of the centerline when the roads were covered in snow. In addition, the distance required for breaking decreases with the depth of the rumble strips due to its uneven surface in areas with wintry weather [10].

2.4.4 Low Cost

Centerline rumble strips is a fairly inexpensive safety countermeasure to implement. The price per linear foot ranged from \$0.18 per linear foot in Minnesota [4] to \$0.87 per linear foot in Colorado [34]. In Kansas, the price per linear foot varied between \$0.08 and \$0.26 [40], while in Delaware, the costs ranged from \$0.20 to \$0.60 per linear foot, though this estimate did not include traffic control costs [6]. Several factors contribute to the variability of the cost. These factors include: the dimensions of the pattern, as longer strips and deeper cuts require more time to mill; the type of roadway surface, as concrete is more time consuming to mill than asphalt; the volume of traffic, which affects the amount of traffic control devices that are needed; and overall size of installation, as larger projects tend to have lower average costs [40].

Within the United States, though rural crashes account for 40% of all crashes, the annual cost associated with the crashes exceeds \$100-billion, encompassing property damage, personal injuries, and fatalities [21]. However, there exist high benefit-cost ratios associated with centerline rumble strips installation. In addition, a positive correlation was observed between benefit-cost ratios and the AADT of a roadway. In a study examining roadways with centerline rumble strips, all but two of twenty locations exhibited a benefit-cost ratio of greater than 1; these ratios ranged from 1.89 to 39.16 [5]. Consistent with this research, a Delaware three year before and after naïve analysis indicated a 110 benefit-cost ratio [6].

2.5 Concerns of Centerline Rumble Strips

The majority of agencies and anecdotal evidence received various concerns from the public about centerline rumble strips, including excessive external noise; adverse effects to motorcyclists and bicyclists, pavement deterioration, lack of advanced signing of treated sections, and snow/ice removal maintenance issues [39].

2.5.1 Weather Related Concerns

There exists speculation among transportation agencies regarding the effects inclement weather has on roadways where centerline rumble strips are installed. Furthermore, uncertainty exists regarding the effects of inclement weather on the performance and effectiveness of centerline rumble strips [21].

2.5.1.1 Wintry Inclement Weather

In snowy and icy inclement weather, agencies in regions with wintry weather such as the Alaska DOT have noted that snow or ice occasionally compacted into their shoulder rumble strips and persisted for a short time after a storm; however, traffic eventually clears it [39]. When traffic does not clear it, additional passes of the snowplow were needed due to the presence of milled centerline rumble strips. Unlike Alaska, other agencies have had issues in snowy and icy inclement weather [21]. According to Oregon's maintenance crews, their shoulder rumble strips would fill with water, and upon encountering cold weather, would freeze to become a "trench of ice" [9].

In other cases, it was not the weather that affected the strips but rather the operations occurring during the winter season that led to the deterioration of the rumble strips. One case was experienced by maintenance crews in New Hampshire, where rumble strips damage occurred due to the chains fitted on snowplows. When the snowplows inadvertently drove over the shoulder rumble strips, the rumble strips tore the tire chains; at the same time the chains damaged the rumble strips. In response, New Hampshire offset all new shoulder rumble strips farther from the travel lane in order to aid the snow plow wheels from inadvertently driving in the shoulder rumble strips [9]. On the other hand, while snowplow blades cause little or no damage to milled rumble strips, it is suggested to place them at least 8-inches off of the travel lane in order to minimize contact with snowplows [7]. Aside from issues with their chains, snowplow blades were found to scrape raised rumble strips off the pavement surface; therefore raised rumble strips were typically restricted to regions that do not need to worry about snow removal [53]. Typically, however, snowplows' blades were found to cause little to no damage to milled-in rumble strips [21].

A second case displayed that the sand applied during snowstorms in Colorado adversely affected rumble strips. The sand often would not completely obscure the centerline rumble strips, but instead blocked part of the paint stripe at the bottom of the grooves. Over time, the pavement marking on areas with centerline rumble strips wore off quicker than areas without these installations [34]. A similar situation occurred due to the application of other snow removal and anti-freezing agents which were caught in the grooves. In New Hampshire, the collection of these winter maintenance debris often not only blocked, but expedited the deterioration of portions of the pavement marking. This ultimately reduced the retro-reflectivity on centerline and edge line rumble strips. In addition to reduced visibility, during night time, the normally solid lines would look like dashed lines, contributing to reduced driver safety [10]. On the opposite spectrum, Minnesota said that more salt may be needed along sections with centerline rumble strips; here the presence of salt is an acceptable alternative to the presence of ice [21]. Lastly, Oregon experienced issues with sand in that the maintenance crew had a difficult time cleaning the rumble strips of sand from sanding activities after the winter season [9].

Rather, most debris was unable to linger long due to the air turbulence of traffic, particularly from large trucks. Therefore, freezing of pooled water was not a major issue, and pavement deterioration was avoided from this perspective [9]. Similarly, as air movement caused by passing traffic rapidly dries residual water in the grooves, there was no indication of asphalt deterioration caused by the presence of wintry weather [34]. Lastly, issues of ice accumulation in centerline rumble strips were determined to be a “non-issue” in a study performed the Kentucky Transportation Center [23]. This is consistent with the conclusion that the issues of snow, ice, or winter maintenance activities have not had a documented effect on the level of sound generated by the rumble strips. In any case, the benefits were determined to outweigh the disadvantages of installing shoulder rumble strips or centerline rumble strips in areas that receive snowy and icy inclement weather [34].

2.5.1.2 Wet Inclement Weather

Other weather related concerns derive from wet weather conditions. In wet inclement weather, there have been theories that the water pooling in the strips may potentially accelerate pavement deterioration due to the increased surface area of exposed pavement [54]. From a NCHRP survey, 15 of 24 responding agencies answered that water accumulation had no effect on pavement deterioration; seven replied that they did not know, and two replied that there was an effect. In the states that indicated an effect, there was not a clear reason for pavement deterioration aside from speculation [39]. Furthermore, it was believed that standing water in milled-in rumble strips is worse with a smaller cross slope. One route in New Mexico had rumble strips installed on the roadway next to a narrow median and was noted to have an issue with standing water. This, in turn, led to concerns about hydroplaning or icing. However, there have been several publications that state the opposite of this relationship. One discussion indicated that in order generate enough force to pull the water out, a combination of a significant volume of trucks and high speeds of passing traffic must exist [9]. According to a FHWA Technical Advisory on shoulder and edge line rumble strips, traffic flow near the rumble strips was satisfactory in keeping water from accumulating and retaining in the strip [46]. Nonetheless, agencies have noted that pooling or standing water has led to no reduction in effectiveness of the rumble strips [2].

Where there are deterioration concerns, there are a number of remedies that can be applied; most remedies are not solely applicable for pavements with rumble strips, but provide enhanced benefits when compared to pavements without rumble strips [54]. Asphalt fog seal can be placed over milled-in rumble strips to reduce its oxidation and moisture penetration [47].

2.5.1.3 Freeze-Thaw Cycles

Other possible weather related issues may arise due to freeze-thaw cycles of water collecting in the grooves, which may be exacerbated in pavements with rumble strips due to the increase in surface area [9]. Field tests, however, refute this hypothesis, instead revealing that the vibration and action of wheels passing over and near rumble strips knock debris, ice, and water out of the grooves. The long term effects of freeze-thaw cycles have not been investigated [5].

2.5.2 Non-Weather Related Concerns

While weather may exacerbate issues relating to centerline rumble strips, the mere presence of centerline rumble strips has raised concerns regarding adverse effects on the roadway.

2.5.2.1 Pavement Deterioration

Several papers and agencies have expressed concerns about pavement deterioration and its related maintenance issues distinct from weather. In one instance, the Kentucky Transportation Center held a meeting with maintenance personnel from three different districts within Kentucky to specifically address maintenance issues. It was found that pavement deterioration existed along the centerline joint on two of the three studied highways; the roadway material was not specified. However, the result was concluded to be due to a retrofit application and pavement performance was poor prior to rumble strips placement [23].

In regard to installations on concrete pavement, Nebraska advises not to place the centerline rumble strips on the roadway joint, but rather on the south side of the striping on east-west highways, and east side of north-south highways. Michigan does not have much experience of centerline rumble strips on concrete, but in several regions, the presence of milled-in centerline rumble strips on centerline joints of old Portland cement concrete was specifically not advised. Still other agencies, with the disclaimer that the installations were still too new and that any deterioration may be present with more time, were not aware of deterioration on concrete joints. In response, several state agencies have policies regarding the depth and age of potential places to install centerline rumble strips; these are shown in Table 3 [21].

Table 3: Sample of State Centerline Rumble Strips Policies [21]

State	Min. Pavement Depth (in.)	Min. Pavement Age (years)
Alaska	2	No
Delaware	Requires consultation of pavement management section	
Louisiana	2.5	7
Kansas	Pavement in good condition	
Louisiana	2	≥ 10
Maryland	Pavement in good condition	
Michigan	Engineering judgment	
Minnesota	Engineering judgment	
Mississippi	Considering for new pavement in future	
Missouri	1.75	New overlays
Nebraska	No	New pavement
Oregon	Pavement in good condition	
Pennsylvania	1.5	> 1
Texas	2	No
Washington	Pavement is structurally adequate	

In a study conducted in Hokkaido, Japan by the Civil Engineering Research Institute for Cold Region, researchers have noted that spalling began to occur around the fourth year after centerline rumble strips installation, sometimes exposing the pavement joint. This relationship to centerline rumble strips is unclear however, and was ultimately attributed to the thinness of the pavement overlay. When the pavement overlay was not the issue, researchers have suggested that spalling can be reduced and water penetration can be prevented by sealing the joint with the thermoplastic used for the centerline marking [10].

Milled-in rumble strips have occasionally been associated with accelerated pavement deterioration, leading to continuous ruts and large areas of pavement delamination. Despite over one thousand miles of milled-in rumble strips installed, Washington State DOT (WSDOT) has noted that pavement is not negatively affected in most installations. Their hypothesis was similar to aforementioned cases: poor pavement existed prior to centerline rumble strips installation. This was found in two types of pavement: bituminous surface treatment pavement and hot mix asphalt pavement with low density, particularly along longitudinal joints. WSDOT's response was that rumble strip installation should be avoided in open-graded pavements, the adequate pavement structure and thickness must exist, and that it may be necessary to remove and inlay existing rumble strips prior to resurfacing. Similar with other agencies, WSDOT's design manual mentions that the roadway pavement must be structurally adequate to support milled-in rumble strips [8].

2.5.2.2 Roadway Visibility

As centerline rumble strips are often installed along the centerline, there is a concern for the potential of decreased visibility of road striping [21]. While night visibility may be improved due to the reflection of the light from vehicles' headlights onto the far-side of the groove, day time visibility may be affected. In addition, the nature of depressed centerline rumble strips leads to accumulation of debris, such as salt and sand, in the grooves [31]. This is particularly a problem in states that experience wintry weather; though the debris does not completely fill the grooves, it does obscure part of the paint striping at the bottom, leading to reduced visibility of the paint markings during the day and making the solid lines look like dashed lines [31, 34]. Furthermore, field reviews show that the paint wears off on the pavement between the grooves than areas without centerline rumble strips. Fortunately, it was found that passing traffic tended to clear the grooves of debris [34].

2.5.3 General Public Concerns

In addition to physical concerns, centerline rumble strips pose issues from members of the general public, including motorists who travel on roadways with centerline rumble strips and residents who live near these roadways.

2.5.3.1 Motorcyclists and Bicyclists

The primary concern regarding cyclists is the perception of danger when riding over the grooves of rumble strips. Depending on the mode, cyclists are not expected to hit the centerline rumble strips often [10]. Even then, intermittent gaps in spacing may help bicyclists cross travel lanes if needed to minimize discomfort from the associated excessive vibration [21]. Two experiments regarding motorcyclists and bicyclists and rumble strips were conducted in Hokkaido, Japan, in 2002 and 2003. Through video recording and analysis, no dangerous driving or riding was identifiable. However, a questionnaire revealed that some drivers and riders felt in danger when riding on grooves around 0.59-inches (15-mm) in depth. In Hokkaido, a rumble strips depth of 0.472-inches (12-mm) was adopted in response [10].

On the contrary, studies performed in the United States revealed that test track riders did not consider rumble strips to be a hazard. One study, performed by Kansas

State University, evaluated cyclists' response by driving the motorcycles over centerline rumble strips in Colorado and test sections in Kansas. The final opinion was that centerline rumble strips was not a safety problem [42]. A second study, based on a test track in Minnesota, found no evidence that centerline rumble strips were a hazard to 2 or 3 wheeled cycles. In fact, there was no change in throttle, braking, or steering when driving over the strips and no evidence to indicate stability problems. Though a small minority considered the rumble strips to be a nuisance, most riders were neutral towards centerline rumble strips. Despite potential concerns, this study revealed that changes in properties or additional signage were not justified. Rather, it was recommended that new cyclists become aware of the rumble strips early in their experience to insure riders are not alarmed at their first encounters [28].

2.5.3.2 Levels of Exterior Noise

The impact from noise is a common source of complaint of residents near the affected roadway as is the potential effect the noise may have on protected wildlife species [48]. Though the noise produced by rumble strips is only intermittent and typically caused by errant vehicles, transportation agencies continue to receive complaints from nearby residents. As mentioned in previous sections, greater groove depth and width increases interior noise and vibration. Therefore, while any deepening or widening of the grooves would directly benefit the motorist, these changes come at an expense to the surrounding environment. In one instance, a shoulder rumble strips installation was heard over 250-feet away at a level above 80 dB [39]. In Connecticut, the local transportation agency removed their installation of centerline rumble strips in response to complaints of excessive noise from nearby residents [31]. In Colorado, a centerline rumble strips installation on U.S. Forest Service land led to complaints regarding noise [34].

As a result, some agencies have factored the issue of noise into their policies, recommending that minimum distances from houses and businesses should be considered [21]. These minimum distances range from 200-feet to 650-feet from the center of the highway [2, 21]. On the contrary, though centerline rumble strips did raise the noise level, some property owners concluded that its presence made driving safer and suggested they are willing to accept the levels of noise [21, 34].

2.5.3.3 Driver Behavior

Though the presence of centerline rumble strips is to act as a countermeasure for drivers who may inadvertently cross the centerline, it has been hypothesized that the presence of the centerline rumble strips may negatively influence the lateral position of drivers, causing motorists to operate closer to shoulders and leading them to make erratic maneuvers [21]. This can be attributed to the fact that many motorists dislike the sound and vibration of rumble strips, while others believe that rumble strips could cause damage to their vehicles [7].

Another unintended consequence of centerline rumble strips is driver unfamiliarity, especially in combination with drowsiness or inattention. This unfamiliarity has led nearly one-third of motorists make an initial leftward correction of the vehicle upon encountering centerline rumble strips. This reaction occurred in approximately one-fifth of the time on tangent roadway segments to over one-third of the time on curved roadway segments. It is theorized that drivers react this way due to familiarity with shoulder rumble strips [31].

A third example of driver behavior modification is that while the centerline rumble strips prevents collisions where it is installed, the problem of head-on collisions still exists and may simply be transferred to areas further down the roadway without centerline rumble strips [6].

2.6 Current State of Practice

As of 2003, roughly 20 states have installed centerline rumble strips, with at least 18 states considering their implementation [2]. By 2005, an estimated 2,300-miles of centerline rumble strips had been installed throughout the United States as well as in three Canadian provinces, with 2,100-miles on two-lane, two-way undivided highways [37]. Results from a survey completed in 2011 indicated that at least 36 states have installed centerline rumble strips, with a combined mileage of over 11,000 miles. These installations ranged from a three-mile stretch in Delaware to over 3,200-miles in Pennsylvania [21].

As mentioned in earlier sections, centerline rumble strips designs and practices vary greatly among state transportation agencies. In some states, there is a minimum lane width required, while in other states, there is a minimum roadway width required. Still other states have no official recommendations based on the lane width, roadway width, or shoulder width [37]. Table 4 highlights some typical centerline rumble strips dimensions.

Table 4: Typical Dimensions of Roadways with Centerline Rumble Strips [37]

Highway Dimension	Maximum	Minimum	Average
Number of Rows of CLRS	2	1	1.2
Minimum Lane Width (ft)	12	10	11.2
Minimum Cross Section Width (ft)	30	20	24.2
Minimum Shoulder Width (ft)	6	0	3

2.7 Safety Analyses

The most popular method of safety analysis is the before-after study, which can be conducted in different methods: the naïve before-after method, the control group method, the empirical Bayes method, and the full Bayes method. Each of these methods compare observed crash data collected in the period before a safety treatment installation with observed crash data collected in the period after a safety treatment installation [25].

2.7.1 Naïve Before-After Method

The simplest technique for an observational before-after study is the naïve before-after method. In this method, the crash frequencies of treated sites in the period before treatment implementation ($crashes_{BEFORE}$) is compared to the crash frequencies of the period after implementation ($crashes_{AFTER}$); the difference between $crashes_{BEFORE}$ and $crashes_{AFTER}$ is considered the safety effect of the countermeasure [3]. The concept of the naïve before-after evaluation lies in the assumption that nothing has changed from the before period to the after period except for the treatment; therefore, $crashes_{BEFORE}$ should be a good estimate $crashes_{AFTER}$ if $crashes_{AFTER}$ is less than the estimate, then the treatment is effective [35]. However, this assumption is inherently flawed, and several factors make the naive before-after method questionable [19].

Two studies conducted when centerline rumble strips were in its infancy in the United States utilized the naïve before-after method to evaluate the safety effectiveness of centerline rumble strips. The first study, conducted in Colorado, used the naïve before-after method to analyze the effectiveness of centerline rumble strips constructed on a 17-mile two-lane, two-way, mountainous section in 1996. Here, researchers collected crash data and compared similar periods from before and after centerline rumble strips installation in order to account for bias from seasonal variations in weather and traffic. With this data, conclusions were derived by directly comparing $crashes_{BEFORE}$ to the $crashes_{AFTER}$ [34]. The second study, conducted in Delaware, used the naïve before-after method to analyze the effectiveness of centerline rumble strips constructed on a 2.9 mile two-lane, two-way highway in 1994. Unlike the Colorado study, researchers here compared the average number of crashes per year before installation to the average number of crashes per year after installation. In this case, the before period consisted of three years, while the after period consisted of eight years [6]. Both studies distinguished crashes by crash types and collected AADT data.

In both of the examined studies, the number of crashes was reduced by upwards of 30%. For head-on collisions, the Colorado study showed a 34% decrease in number of crashes, while the Delaware study showed a 95% decrease in rate of crashes per year, as seen in Table 5 and Table 6. While these results led to the conclusion that centerline rumble strips were an effective countermeasure, changes in other causal factors such as traffic volume or general crash trends were not statistically considered. Furthermore, the statistical significance of the results was not determined. Instead, both of the studies emphasized the effectiveness of centerline rumble strips as the $\text{crashes}_{\text{AFTER}}$ were substantially less than the $\text{crashes}_{\text{BEFORE}}$ despite increasing traffic volumes [6, 34].

Table 5: Colorado Centerline Rumble Strips Safety Evaluation Results [34]

	Before Period 7/92 – 3/96	After Period 7/96 – 3/00	Percent Change
Head-on accidents	18	14	--
Head-on accidents per million vehicles	2.91	1.92	-34%
Sideswipe Opposite Direction	24	18	--
Sideswipe accidents per million vehicles	3.88	2.46	-36.5%
Average ADT	4,628	5,463	+18%

Table 6: Delaware Centerline Rumble Strips Safety Evaluation Results [6]

	Before Period 8/91 – 7/94	After Period 12/94 – 11/02	Percent Change
Head-on	2/year	0.1/year	-95%
Drove left of center	2/year	0.8/year	-60%
Property damage	6.3/year	7.1/year	+13%
Injury	4.7/year	4.9/year	+4%
Fatal	2/year	0/year	N/A
Total	13/year	12/year	-8%
Average ADT	16,500	22,472	+4% yearly

Though the naïve before-after method allows for a quick and simple safety effectiveness evaluation, safety estimates based only on crash counts are subject to regression-to-the-mean bias, which is known to produce inflated estimates of safety effectiveness [19]. Regression-to-the-mean describes the phenomenon that, barring changes in physical or traffic characteristics at a site, the number of crashes at that site per unit of time will naturally tend to fluctuate about a mean value due to the random nature of crash occurrence [32]. The phenomenon is particularly pronounced when sites for treatment are selected as a result of the unusually high number of crashes in recent years, also known as "selection bias" [18]. Because the number of crashes was unusually high, even without treatment, the crash rate was likely to move towards the mean in the following years, leading to incorrect assumption that the treatment was effective [32]. Other issues with the naïve before-after method include the fact that traffic, weather, and other factors change over time, other treatments may have been implemented concurrent with the study period, and that the probability of reportable accidents being reported changes over time [18].

2.7.2 Cross-Sectional Study

The cross-sectional study allows the comparison of roadways with a treatment and similar roadways without the treatment. From comparing the crash experience of both sets of roadways, the effectiveness of the treatment is determined by the difference in crash experience. From this study, a crash modification factor (CMF) can be estimated as the ratio of the average crash frequency for sites with treatment to the average crash frequency of sites without the treatment. This type of study is particularly useful for estimating CMFs when there are insufficient instances where the treatment was applied for a before-after study to be conducted. The drawback, however, is that it is often difficult to collect data for enough locations that are similar in all factors to the roadways with treatment. Because of this, unknown factors cannot be properly accounted for, and thus inferences made from the CMFs should be treated with caution. Ultimately, the before-after method is preferred [16].

2.7.3 Comparison Group Method

As causal factors that influence safety are often unrecognized or unmeasured, the safety effectiveness of a treatment may be skewed if such factors are unaccounted for. Therefore, in order to account for these unknown factors, a group of roadways with similar characteristics to those of the treated roadways must be selected. In this manner, the behavior of crashes of the comparison group can be related to the behavior of crashes in the treatment group based on the assumption that the ratio of the expected number of crashes before and after the treatment installation would be same for both groups [18]. However, though the comparison group method, as opposed to the naïve before-after method, can theoretically eliminate regression-to-the-mean bias and selection bias, the comparison group needs to have the same characteristics as those of the treatment group, including sample mean and variance. Thus, similar to the cross-sectional study method, finding suitable sites for the comparison group may be very difficult [25]. In addition, one characterization of regression-to-the-mean bias, the presence of unusually high crash frequency, could still apply to the comparison group, potentially leading to an over-estimation of the safety effectiveness of the countermeasure in the treatment group [35]. Regression-to-the-mean, however, can be addressed if both the treatment and comparison sites are matched on the basis of the observed crash frequency in the before period, albeit very difficultly. Where there is no regression-to-the-mean and a suitable comparison is available, the comparison group methodology may be a simple alternative to the empirical Bayes approach [16].

In a study conducted in Massachusetts, three roadways with centerline rumble strips (study group) and seven comparison roadways without centerline rumble strips (comparison group) were evaluated. The comparison sites were selected with roadway geometry, cross-section, travel speeds, traffic volumes, the influence of traffic flow on crashes, and climatic conditions in consideration. These sites were then used to estimate the change in the number of crashes that would have occurred if the centerline rumble strips were not installed on sites within the treatment group. As seen in Figure 6, many of the sites in the comparison group experienced either an increase the number of crashes, while the sites in the treatment group experienced a slight decrease or remained consistent [31].

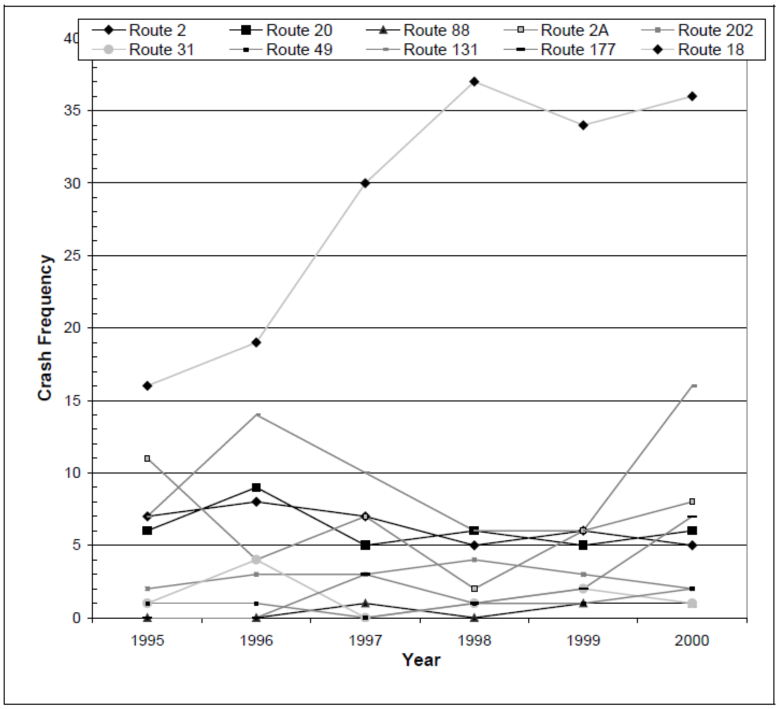


Figure 6: Crash Frequency of Study and Comparison Groups [31]

Of all the sites studied, an empirical Bayes approach following the comparison group evaluation did not produce statistically significant results. In conclusion, the results from this study revealed that there was no statistical evidence that centerline rumble strips significantly reduced crash rates [31].

2.7.4 Empirical Bayes Before-After Method

The empirical Bayes methodology enables a more precise estimation of the number of crashes that would have occurred at an individual treated site in the after period had a treatment not been implemented [16]. In addition, the empirical Bayes method addresses several issues of the aforementioned methods: it increases the precision of estimates when a study is limited to data from less than three years, and it corrects for the regression-to-the-mean bias [19]. As mentioned in Chapter 2.7.1, the regression-to-the-mean phenomenon tends to produce inflated results. In order to counter this, the true underlying accident rate must be estimated, which forms the foundation of the empirical Bayes method. The safety effectiveness study can then be based on the model rather than the raw crash data [32].

The basis of this method is the use of crash information observed in the before period of treated sites and reference sites. This data is then used to predict the number of crashes expected after treatment, which is in turn compared to the actual observed number of crashes after treatment. In order to arrive at this estimation, the reference sites are first used to derive a safety performance function (SPF), which relates the crash experience of the reference sites to their traffic volume and physical characteristics, such as roadway geometry [16]. While characteristics such as lane width and road grade may be included in the SPF, if these characteristics remain unchanged during the duration of the study, their value is immaterial and may cancel out [18].

Though the premise of empirical Bayes is straightforward, studies using this method vary in their methodology. In a study conducted in Kansas, the safety effectiveness of centerline rumble strips in that state was determined through the empirical Bayes method, and consisted of first selecting roadways that were similar in nature (reference sites) to the roadways with centerline rumble strips (study sites). These roadways were selected on the basis of similar AADT, shoulder width, lane width, shoulder rumble strips presence, and route classification and were then used to fit SPF models. In order to estimate various types of crashes and scenarios, multiple SPFs were developed, allowing the estimation of the total correctable crashes, cross-over crashes, run-off-the-road crashes, and crashes that involve fatalities or injuries [22]. The procedure used to develop the SPF in this study, and in many other studies, was the GENMOD procedure in the Statistical Analysis System software. Once the SPF was calculated, the average crash frequency per year in the before period was estimated and then used to project the average crash frequency per year into the after period. Lastly, the estimated number of crashes in the after period was compared to the observed number of crashes in the after period and the effectiveness was determined. Of the four crash types analyzed in this study, all four empirical Bayes results were deemed comparable to the naïve before-after results [1, 22, 44].

CHAPTER 3

SURVEY

As part of GDOT's Safety Action Plan, nearly 200 miles of centerline rumble strips were installed in 2005 and 2006 [43]. Centerline rumble strips have shown promising results in other states, which various studies and agencies acknowledge. However, after these installations, GDOT began receiving reports of pavement deterioration at sites with centerline rumble strips, and consequently suspended their centerline rumble strips program. To investigate this issue and other potential adverse effects of centerline rumble strips, a survey was developed and sent out to the Department of Transportation agency of every state via email. The survey and questionnaire results are outlined in Appendix A. At the time of this study, the survey had a 56% response rate and was still open for responses.

3.1 Survey Contacts

Most of the points of contact information were not explicitly stated on the agency's DOT website; no official contact person specializing in centerline rumble strips for each state DOT was listed online. Therefore, the survey contacts list was built by searching various state DOT agencies' websites for persons who specialized either in safety, traffic, or operations. If no contact could be found, a form was submitted to the agency requesting that a contact be assigned to assist in this survey. Once a preliminary list of contacts was established, the survey was sent out to each of the 50 state DOTs. Initially, the contacts were given one month to complete the survey; this deadline has since been lifted. At the time of this study's conclusion, 28 contacts have responded to the survey, representing 28 state DOTs highlighted in Figure 7.

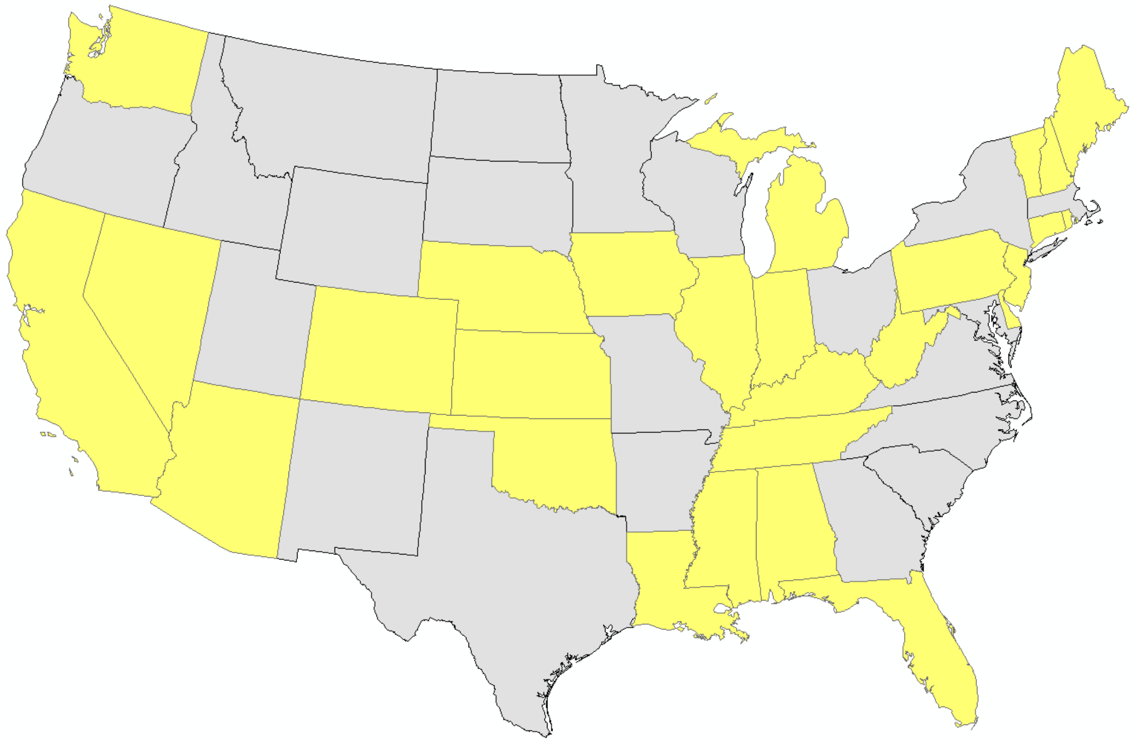


Figure 7: Survey Responses: Yellow - Received Response; Gray – Awaiting Response

The 28 responders varied in expertise. Figure 8 highlights the results; the majority of the responders indicated that engineering was their area of expertise, while less than half indicated that safety was their area of expertise. As only a few indicated that maintenance was their area of expertise, there may be potential bias of results in questions regarding maintenance.

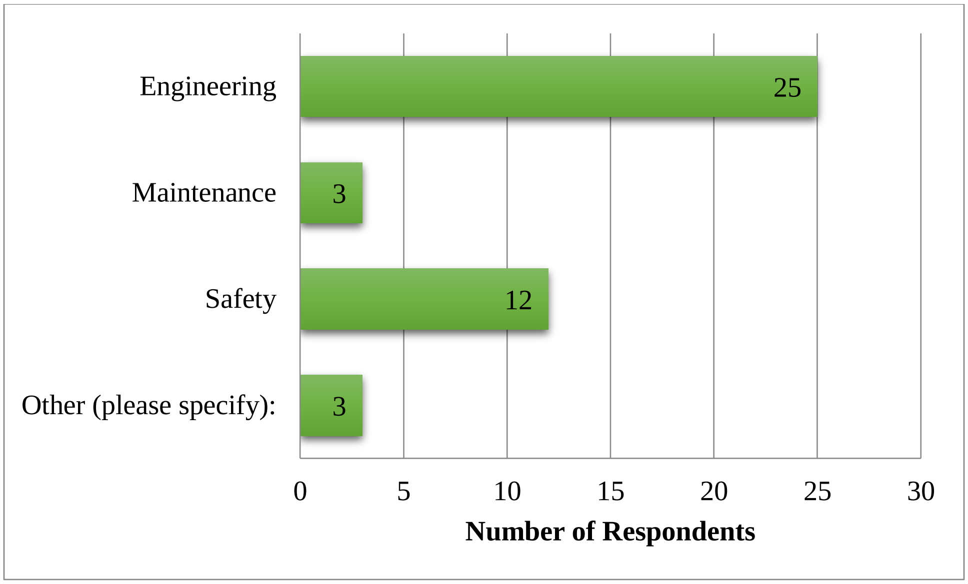


Figure 8: Respondents' Area of Expertise

The respondents varied in job titles, including Transportation Engineers, Safety Operations Engineers, Markings and Delineation Engineers, Pavement Engineers, and Project Managers. Occasionally, the initial person contacted was not the most appropriate person to complete the survey; in these situations, the initial person referred the survey to another contact to complete the survey.

3.2 State of Centerline Rumble Strips

At the time of this study, all 28 state DOTs represented in this survey had installed centerline rumble strips within their jurisdiction. Nearly two decades after the first installation of centerline rumble strips, 18% of responders considered that their state DOT has extensively installed centerline rumble strips on their roadways [6]. A breakdown of this answer is shown in Figure 9.

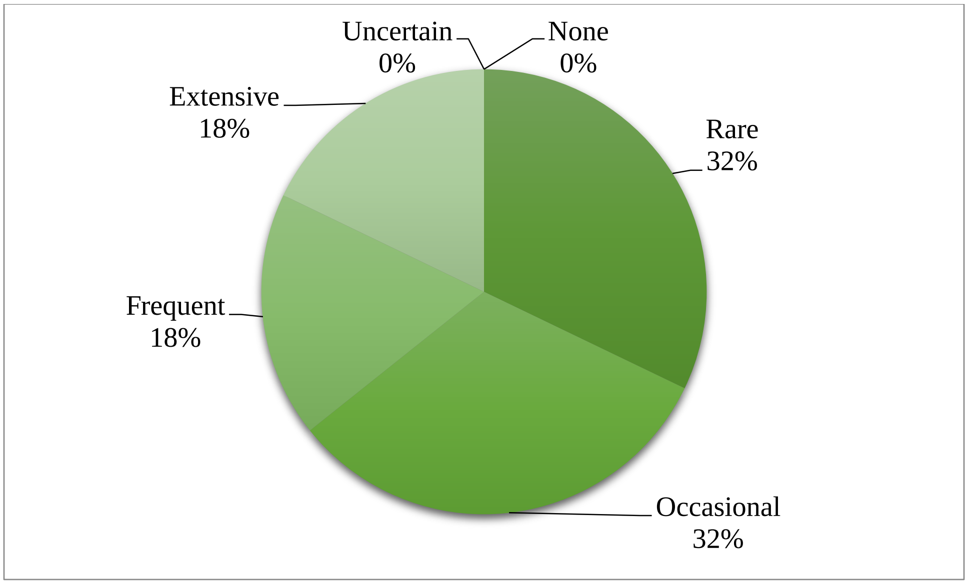


Figure 9: Prevalence of Centerline Rumble Strips

Of the current installations, most of the installations were constructed using the milled-in technique, in which grooves were cut into the ground, as seen in Figure 10.

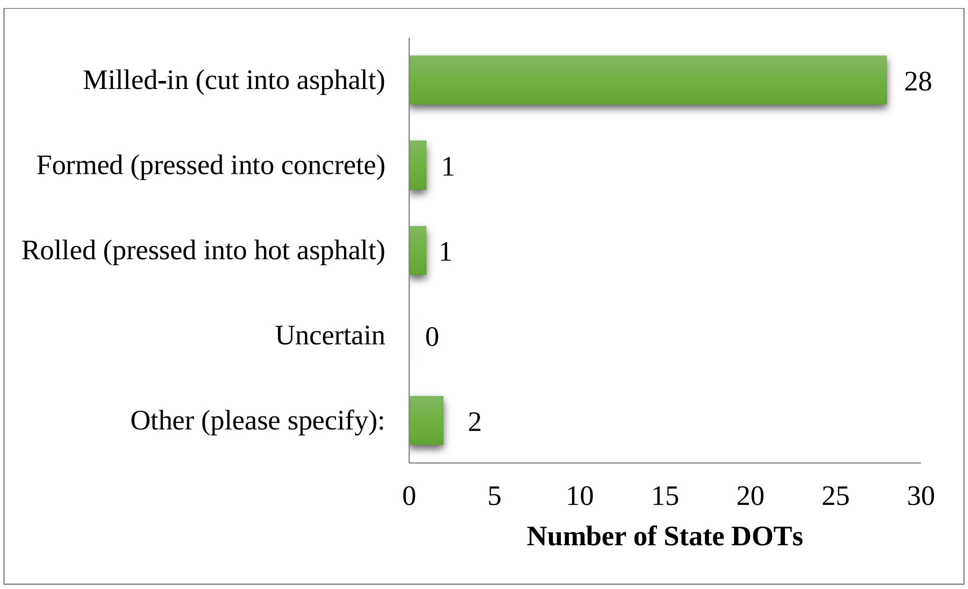


Figure 10: Methods Used to Install Centerline Rumble Strips

Of the 28 state DOTs, all but one stated that the milled-in technique was the predominant method used to install centerline rumble strips. In addition to installation technique, the environment of the roadways on which centerline rumble strips were installed was of interest. Figure 11 reveals that the majority of states installed centerline rumble strips on rural roadways only, with a few states installing centerline rumble strips in urban areas.

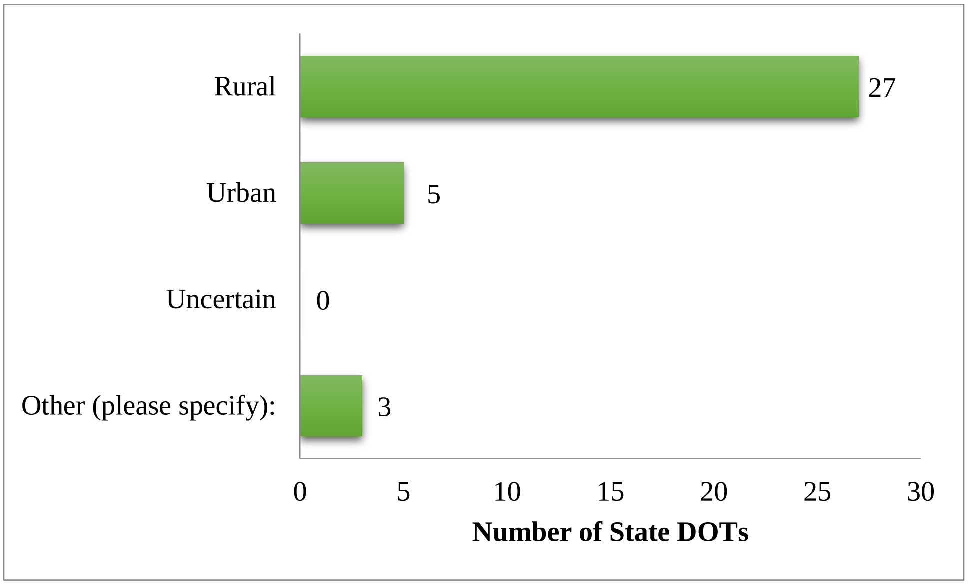


Figure 11: Roadway Environment of Centerline Rumble Strips

Other responses specified that centerline rumble strips were installed outside of incorporated city limits, in areas with lower housing densities, on roadways of at least 50 mph, or in urban areas only as a response to unusually high cross-over crashes.

3.3 Adverse Effects of Centerline Rumble Strips

In investigating potential adverse effects of centerline rumble strips, states were allowed to pick five preselected known concerns as well as submit their own response. The five preselected choices were chosen as each issue was mentioned in the literature review; they are as follows:

- Accelerated pavement deterioration (e.g., increased cracking)
- Pavement failure (e.g., section loss)
- Decreased visibility of paint striping (e.g., obscured by accumulated sand, decreased retro-reflectivity)
- Residential issues (e.g., excessive noise)

- Other adverse issues not listed above

Of the 28 states that responded, 10 states mentioned that they have experienced adverse issues associated with centerline rumble strips.

3.3.1 Accelerated Pavement Deterioration

Accelerated pavement deterioration is indicated by a higher rate of deterioration on roadways with centerline rumble strips than if the centerline rumble strips were not installed. This could be characterized by an increase in cracking, trenching, or rutting of the pavement surface. Of the 10 state DOTs that have experienced adverse effects, five stated that accelerated pavement deterioration occurred as a result of centerline rumble strips; the extensiveness of this issue ranged from rare to occasional. The majority of these issues occurred on asphalt roadway, with one occurrence on concrete roadway and one on bituminous surface treated roadways with low AADTs. In addition to the causes identified by state DOTs for this issue highlighted in Figure 12, some state DOTs simply had a general issue with centerline joint deterioration due to flawed construction processes, of which centerline rumble strips may not be the primary contributor to this issue. Lastly, some state DOTs have concerns regarding accelerated pavement deterioration due to water ponding in the centerline rumble strips grooves and additional freeze/thaw stress on the joint, however evidence of the issue has not been documented.

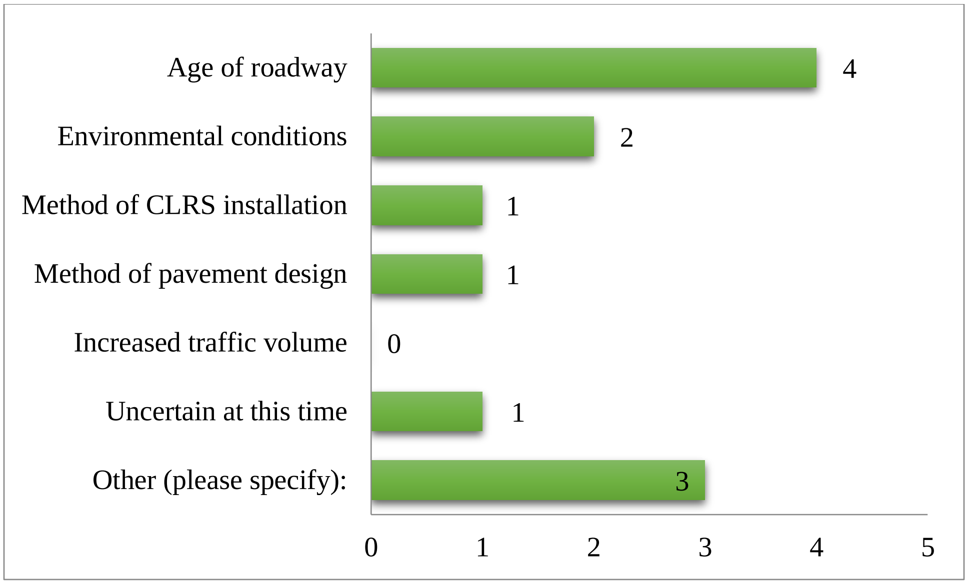


Figure 12: Causes of Accelerated Pavement Deterioration on Roadways with CLRS

The responses to accelerated pavement deterioration varied from state DOT to state DOT, with some state DOTs responding in several ways. State DOT responses to accelerated pavement deterioration are shown in Figure 13.

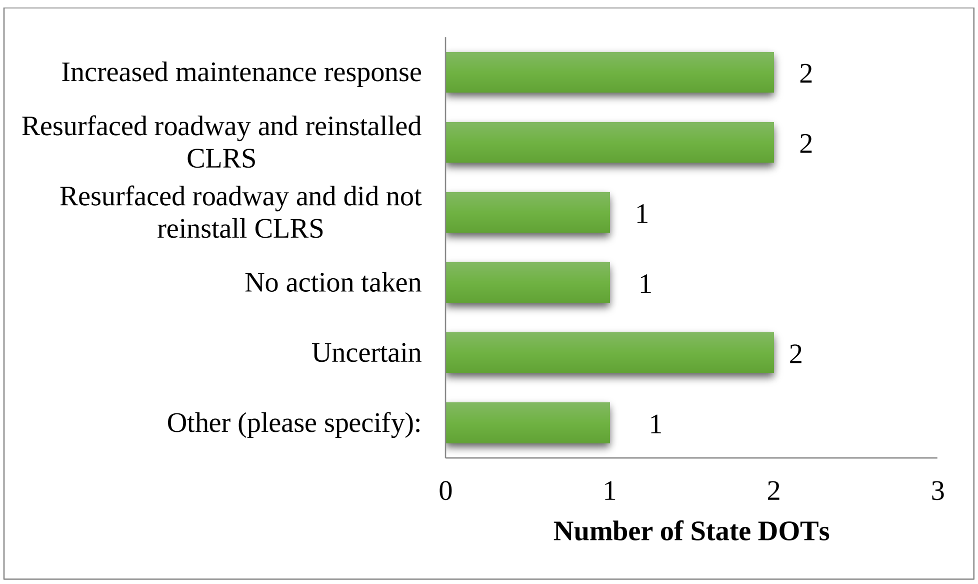


Figure 13: State DOT Responses to Accelerated Pavement Deterioration

While at least one state DOT removed centerline rumble strips altogether from the roadways affected by this issue, some state DOTs have implemented innovative practices to avoid accelerated pavement deterioration, such as the installation of dual, 8-in wide rumble strips on both sides of the centerline joint.

3.3.2 Pavement Failure

Pavement failure is characterized by section loss, which is characterized by pavement falling apart or crumbling away at the centerline rumble strips; three state DOTs have experienced this issue. The causes of this issue as indicated by the respondents are shown in Figure 14.

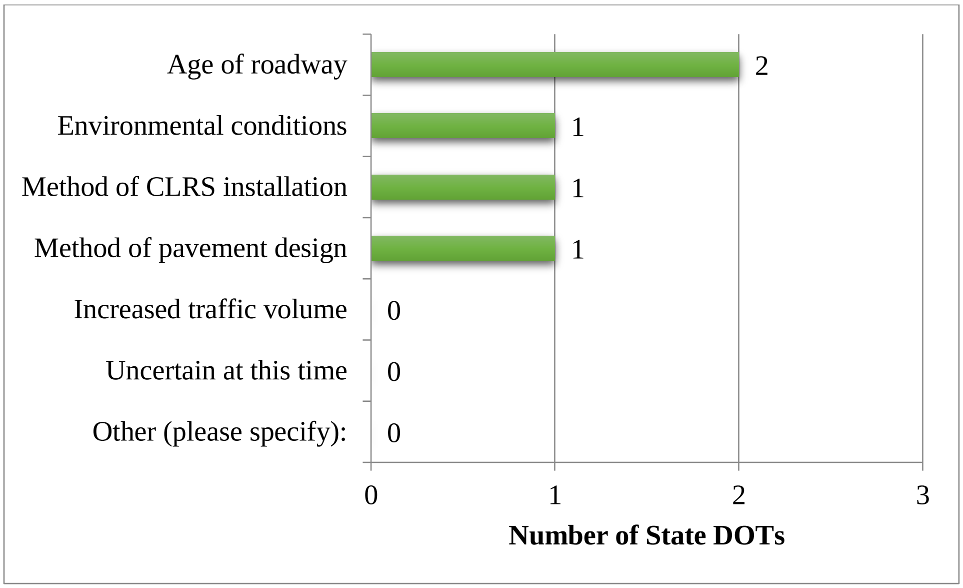


Figure 14: Causes of Pavement Failure on Roadway with CLRS

All cases of pavement failure occurred on asphalt roadway. Similar to the issue of accelerated pavement deterioration, pavement failure was typically thought to be attributed to the old age of the roadways on which the centerline rumble strips were installed with some citations of environmental conditions, the method of centerline rumble strips installation, and the method of pavement construction as factors. Lastly, the agencies' responses to the issue of pavement failure varied from the increasing of maintenance response, to the resurfacing of the roadway and reinstallation of centerline rumble strips, to the resurfacing of the roadway without the reinstallation of centerline rumble strips.

3.3.3 Noise

Commonly cited in the literature, the adverse effect of noise has been a major cause of concern of centerline rumble strips. Seven of the ten state DOTs that experienced issues experienced noise concerns, with extensiveness ranging from rare to occasional. All but one state DOT indicated that asphalt pavement was associated with noise; the other response was bituminous surface treatment. Reasons for noise issues included an increase of traffic volume and the presence of centerline rumble strips in passing zones or rural residential areas. The newness of the centerline rumble strips installation was also cited as a reason for noise issues for one state DOT, although noise complaints subsided several months after installation.

Though state DOTs received noise complaints, none of them removed the centerline rumble strips. Rather, the DOTs increased awareness of the safety benefits of centerline rumble strips, refined their installation policy to only install centerline rumble strips in rural areas, or examined possibilities of restriping or re-milling centerline rumble strips.

3.4 Future of Centerline Rumble Strips

As some state DOTs have experienced problems, most have some reservations regarding installation of additional centerline rumble strips, shown in Figure 15. These issues increased maintenance associated with centerline rumble strips, potential adverse effects to cyclists due to their small wheel base, adverse effects on driver behavior by causing motorists to keep a distance from the centerline, and drive closer to the shoulder, and excessive noise produced when a vehicle drives over the rumble strips.

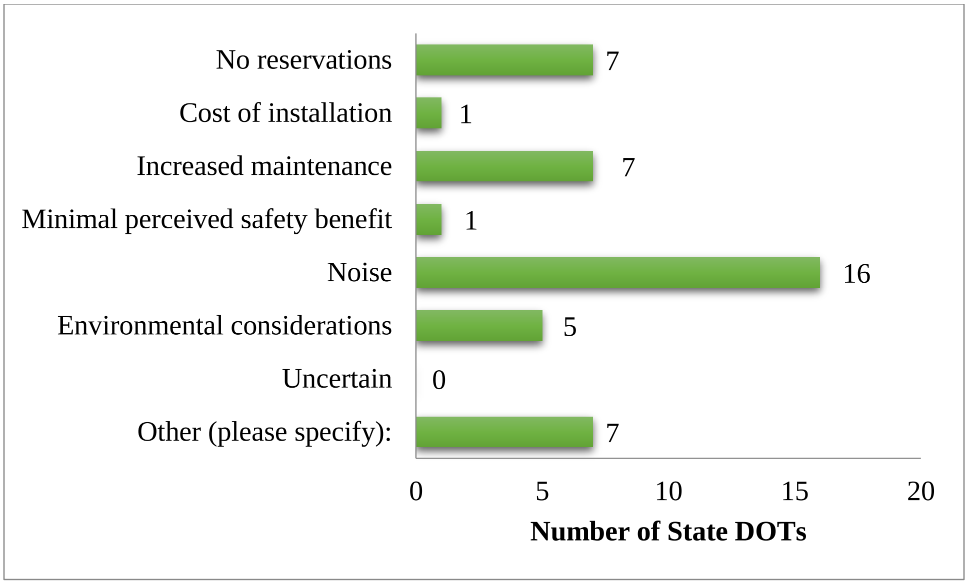


Figure 15: Reservations Regarding Centerline Rumble Strips Installation

Despite reservations, nearly every responding state DOT was either planning additional centerline rumble strips, with many currently constructing centerline rumble strips, as shown in Figure 16.

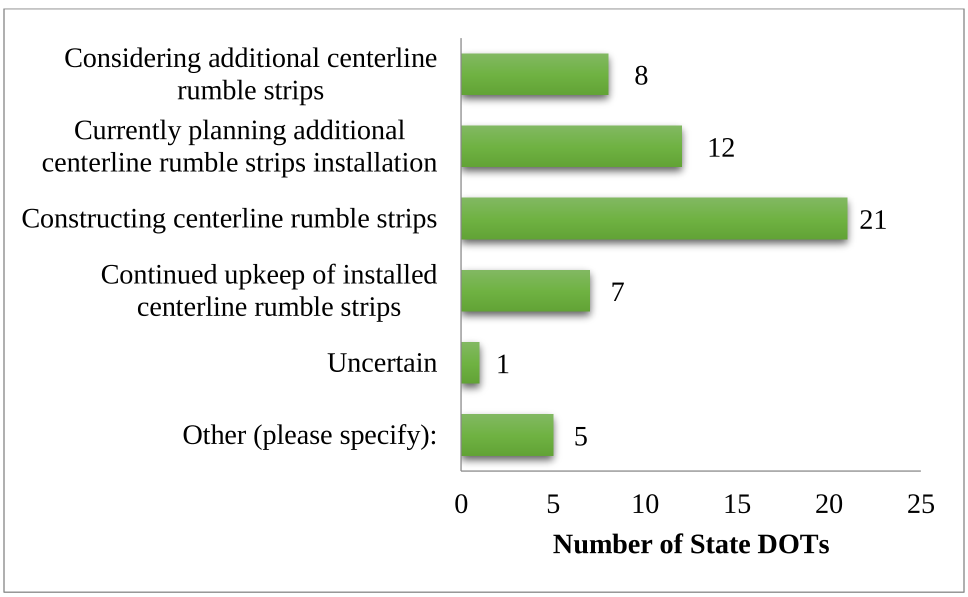


Figure 16: Future of Centerline Rumble Strips Program

From this survey, it is clear that state DOTs believe centerline rumble strips have been shown to be effective at reducing cross-over crashes and are relatively inexpensive. In addition, state DOTs indicated that they will continue to invest in centerline rumble strips in the years to come.

CHAPTER 4

METHODOLOGY

This study consists of three portions: development of a candidate site list for the study, two before-after analyses, and a comparative analysis. Therefore, this methodology section is partitioned into three sections; the second and third sections detail the three types of analyses conducted to determine the safety effectiveness of centerline rumble strips in Georgia.

4.1 Site Selection

Throughout the early 2000s, GDOT proposed and constructed centerline rumble strips on various roadways throughout the state as a part of GDOT's Safety Action Plan [43]. By 2006, there were nearly 200 miles of centerline rumble strips installed, primarily on rural two-lane, two-way roadways.

4.1.1 Transportation Project Information (TransPI)

An initial list of centerline rumble strips projects was compiled using GDOT's Transportation Project Information (TransPI) website. TransPI, a publicly accessible web-based database detailing Georgia's transportation projects was initially developed in response to the issue of limited or unavailable information regarding GDOT projects. Since its inception, project managers and engineers submitted project information into the TransPI system, allowing users both within and outside GDOT to obtain information regarding transportation projects, including documentation, financial information, and Geographical Information Systems (GIS) views [51]. Figure 17 shows a screenshot of the website as captured in November, 2013.

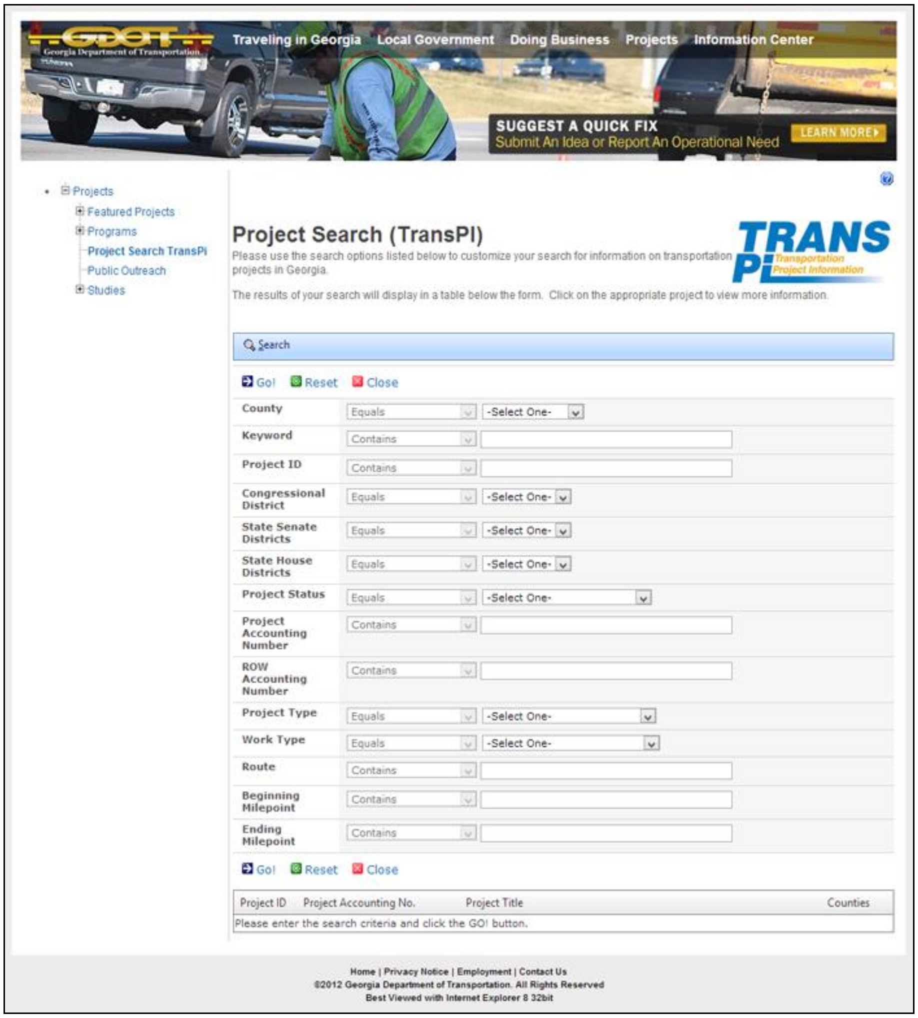


Figure 17: TransPI Internet User Interface [52]

For this study, various search terms were queried using the Keyword field, including "rumble strips", "centerline rumble strips", and "centerline". A list of relevant projects would be returned upon clicking the go button. Table 7 highlights the seven transportation projects found on TransPI where centerline rumble strips installation was involved.

Table 7: Results Obtained from TransPI

Project ID	Project Accounting No.	Project Title	Counties
0006080	-	SR 25 SPUR EAST FM CR 583/SEA ISLAND DR TO E OF SR 25/US 17	Glynn
0006693	CSSTP-0006-00(693)	SR 14|SR 16|SR 154@SEV LOC IN CARROLL &COWETA [CENTERLINE]	Carroll, Coweta
0006945	CSSTP-0006-00(945)	SR 369 FM CHEROKEE CO TO HALL CO – CENTERLINE RUMBLE STRIPS	Forsyth
0006975	CSSTP-0006-00(975)	SR 42@SEV LOC IN HENRY|BUTTS|MONROE-CENTERLINE RUMBLE STRIPS	Butts, Henry, Monroe
0006976	CSSTP-0006-00(976)	SR 204 FM BRYAN COUNTY LINE TO I-95-CENTERLINE RUMBLE STRIPS	Chatham
0007077	CSSTP-0007-00(077)	SR 36 FM SR 74 TO SR 7 & SR 36 FM SR 7 TO I-75	Butts, Lamar, Upson
0007079	CSSTP-0007-00(079)	SR 136 FROM SR 61/US 411 TO DAWSON COUNTY LINE	Gilmer, Gordon, Murray, Pickens
0007080	CSSTP-0007-00(080)	SR 26 FM E OF BULL RIVER BRIDGE TO TYBEE ISLAND CITY LIMITS	Chatham

Within the TransPI pages detailing each project, the project description was examined. If the description mentioned centerline rumble strips, all of the project information available from TransPI pertaining to each installation site was recorded, regardless of how many entries existed per project. For example, Project No. 0007077 had six entries with minor differences; three entries were repeated twice. An example of this preliminary information for one of the seven projects found is shown in Table 8.

Table 8: TransPI Descriptions of Project No. 0007077

Attribute	Description 1	Description 2	Description 3
Project ID	0007077	0007077	0007077
Project Title	SR 36 FM SR 74 TO SR 7 & SR 36 FM SR 7 TO I-75	SR 36 FM SR 74 TO SR 7 & SR 36 FM SR 7 TO I-75	SR 36 FM SR 74 TO SR 7 & SR 36 FM SR 7 TO I-75
Project Manager	Scott Zehngraff	Scott Zehngraff	Scott Zehngraff
Office	Traffic Safety & Design	Traffic Safety & Design	Traffic Safety & Design
County	Butts, Lamar, Upson	Butts, Lamar, Upson	Butts, Lamar, Upson
Congressional District	3	3	3
Project Type	Safety	Safety	Safety
Project Status	Complete	Complete	Complete
Notice to Proceed Date	10/4/2005	10/3/2005	10/3/2005
Construction Percent Complete	63.79%	77.71%	99.42%
Current Completion Date	4/30/2006	5/31/2006	5/31/2006
Work Completion Date	3/21/2006	6/30/2006	6/30/2006
Construction Contract Amount	$293,092.69	$293,092.69	$173,325.77
Construction Contractor	Costello Industries, Incorporated	Costello Industries, Incorporated	Costello Industries, Incorporated
Project Description	INDENTATION CENTERLINE RUMBLE STRIPS ON SR 36 FROM EAST MAIN STREET TO PEACH BLOSSOM TRAIL AND FROM HWY 41 TO I-75 IN DISTRICT 3	INDENTATION CENTERLINE RUMBLE STRIPS ON SR 36 FROM EAST MAIN STREET TO PEACH BLOSSOM TRAIL AND FROM HWY 41 TO I-75 IN DISTRICT 3	INDENTATION CENTERLINE RUMBLE STRIPS ON SR 36 FROM EAST MAIN STREET TO PEACH BLOSSOM TRAIL AND FROM HWY 41 TO I-75 IN DISTRICT 3

Though seven projects were found, the project descriptions within some of the results revealed that some projects included more than one installation site. For example, the project highlighted in Table 8 consisted of centerline rumble strips installation on two separate roadway sections: one on SR 36 from SR 74 to SR 7; the other on SR 36 from SR 7 to I-75. Through an examination of the different project descriptions, at least 11 potential centerline rumble strips installation sites were compiled from TransPI. Also within TransPI, basic descriptions regarding the beginning and ending points of the centerline rumble strips were listed for some projects. These sites and their related beginning and ending descriptions from TransPI are listed in Table 9.

Table 9: TransPI Location Description by Installation Site

Project ID	Centerline Rumble Strips Installation Site	Beginning Description	Ending Description
0006080	State Route 25 Spur	Sea Island Drive/CR 583	State Route 25/US 17
0006693	State Route 14	Herring Road/CR 43	Johnston Circle/CR 7
0006693	State Route 16	Carrolton Bypass	Newnan Bypass
0006693	State Route 154	State Route 54	I-85
0006945	State Route 369	Forsyth County	Forsyth County
0006975	State Route 42	Several Locations in Henry, Butts, and Monroe Counties	Several Locations in Henry, Butts, and Monroe Counties
0006976	State Route 204	Bryan County Line	I-95
0007077	State Route 36	East Main Street	Peach Blossom Trail
0007077	State Route 36	Highway 41	I-75
0007079	State Route 136	State Route 61/US 411	Dawson County Line
0007080	State Route 26	East of Bull River Bridge	Tybee Island City Limits

The presence of centerline rumble strips at these sites were then verified using the descriptions in Google Maps and Google Street View, as seen in Figure 18; every centerline rumble strip installation site obtained from TransPI contained centerline rumble strips.

Figure 18: Google Street View Roadway Verification [15]

Though the majority of the installation sites were obtained from TransPI, information obtained from the database was incomplete or outdated. For example, the information from Table 8 displayed conflicting information: the Project Status was *Complete* for all three entries, yet the Construction Percent Complete was 63.79%, 77.71%, and 99.42%. Because much of the information was incomplete, information taken from TransPI needed to be verified with other sources.

4.1.2 Project Preconstruction Status Reports

In the search for additional information, a visit to GDOT revealed additional information for each project, including the total mileage and various dates associated with the project such as the Management Let Date and the Project Completion Date. At the time of site selection, the Project Preconstruction Status Reports were not accessible through TransPI. Figure 19 shows an example project preconstruction status report.

PRECONSTRUCTION STATUS REPORT

PROJ ID	COUNTY	DESCRIPTION
0006080	Glynn	**SR 25 SPUR EAST FM CR 583/SEA ISLAND DR TO E OF SR 25/US 17** This project consists of installing ground-in-place centerline indentation rumble strips centered about the centerline traffic stripe of State Route 25 Spur East from Sea Island Drive to east of State Route 25/US 17 in Glynn County (MP 6.15 to MP 10.53).

PROJ NO.:	CSSTP-0006-00(080)	**SPONSOR :**	GDOT
MPO TIP #:	BATS 06-01	**PROJ MGR:**	Cameron, Derrick
MPO:	Brunswick	**DOT DIST:**	5
PROJ LENGTH (MI)	3.93	**CONG. DIST:**	1
PROGRAM TYPE:	Safety	**House Dist :**	
TYPE WORK:	Rumble Strips	**Senate Dist :**	
LET RESPONSIBILITY:	GDOT Let		
BIKE PROVISIONS INCLUDED?	N		

Phase	*Fiscal Year Approved*	*Approved FY Estimate*	*Fund*	*Phase Status*
Engineering	2006	$ 5,000.00	Q21	AUTHORIZED

Inflation Included in Estimate

ACTIVITY	*ACTUAL START*	*ACTUAL FINISH*	*PERCENT COMPLETE*
Environmental Approval	**1/5/2006**	**1/5/2006**	100
PFPR Inspection	1/31/2006	1/31/2006	100
FFPR Inspection			0

Right of Way Acquisition Information

Preliminary Parcel Count: **Total Parcel Count:** **Acquired by:** N/R

Figure 19: Preconstruction Status Report for Project No. 0007077

4.1.3 Project Plan Sheets

Per request, GDOT provided the Project Plan Sheets for each project. Information obtained from these project plan sheets pertinent to each centerline rumble strips installation site is tabulated in Table 10.

Table 10: Project Plan Sheets Information for Project No. 0007077

Attribute	Description
Project Number	CSSTP-0007-00(077)
Project ID	0007077
Net Length	29.77
Starting Milepost	MP 8.12
Ending Milepost	MP 0.49
Starting County	Upson County
Ending County	Butts County

The most crucial information was obtained from maps detailing the installation site's location and beginning and ending mileposts; an example is shown in Figure 20. Though the beginning and ending mileposts of each segment were shown, the maps did not correspond to the descriptions from TransPI for several projects. For example, the description of Project No. 0007077 indicated that centerline rumble strips were installed on two separate sections of the roadway as verified through Google Maps and Google Street View. However, the Project Plan Sheet for this project only contained one map and showed one section, as seen in Figure 20. While the information was not always correct, they provided a starting point and assisted in determining the locations of the installation site.

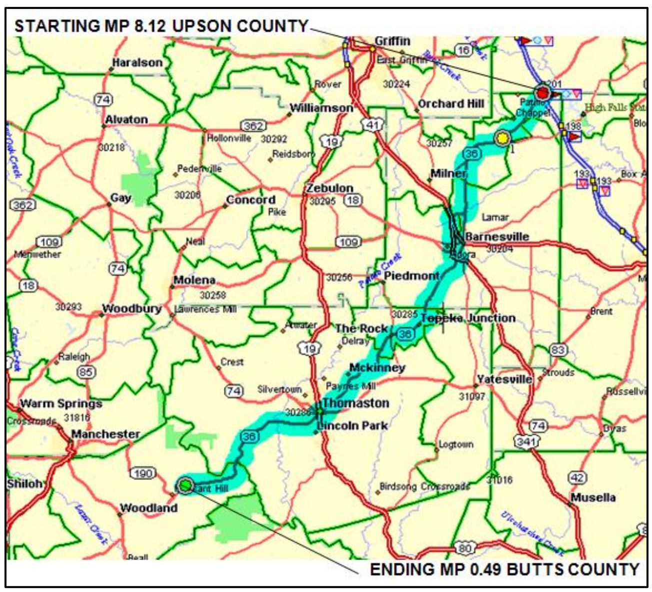


Figure 20: Location Map of Project No. 0007077 from the Project Plan Sheet

Additionally, a Detailed Quantities Estimate was listed in each Project Plan Sheet. The values within this estimate were utilized to verify that the project included centerline rumble strips.

Using the information obtained from the Project Plan Sheets, Google Maps, Google Street View, and Project Preconstruction Status Reports, it was concluded that 10 centerline rumble strips installation sites would be analyzed in this study, down from the list of 11 projects presented in Table 9. Project No. 0006975 was subdivided into two sections to represent the two different segments of roadways with centerline rumble strips. Project No. 0006080 and Project No. 0007080 were eliminated from the study as TransPI listed a "cancelled" status under the Project Completion category. The final list of sites used in this study is listed in Table 11; a map of the project locations within Georgia is presented in Figure 21. Individual site characteristics, including information obtained from TransPI and Project Plan Sheets, are detailed in Appendix B.

Table 11: Final List of Study Sites

Project Number	Description
0006693	SR 14
0006693	SR 16
0006693	SR 154
0006945	SR 369
0006975	SR 42 Section A
0006975	SR 42 Section B
0006976	SR 204
0007077	SR 36 Section A
0007077	SR 36 Section B
0007079	SR 136

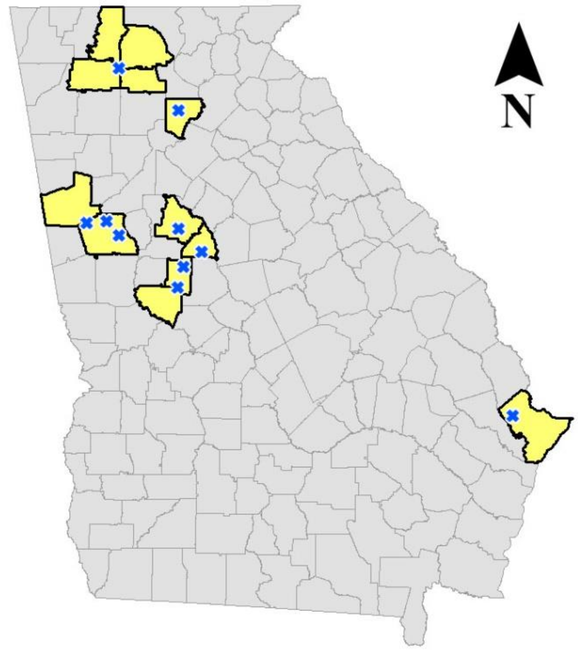


Figure 21: Locations of Centerline Rumble Strips Sites in Georgia

4.1.4 Federal Report of Completed Projects

In order to conduct a before-after analysis, the date separating the two periods must be obtained. For this study, the date separating the periods was derived from the construction periods. From a federal report of completed projects, the construction beginning and ending dates were obtained for each project from the Construction Begin Date and Time Charges Stop Date, respectively. However, these records were inconsistent with TransPI dates, as seen in Table 12. Upon consultation with GDOT engineers, the Time Charges Stop Date was confirmed to be the date construction was completed.

Table 12: Comparison of Important Dates for Project No. 0007077

	Notice to Proceed Date	Current Completion Date
TransPI	10/4/2005	3/21/2006
	10/4/2005	3/21/2006
	10/4/2005	3/21/2006
	10/3/2005	6/30/2006
	10/3/2005	6/30/2006
	10/3/2005	6/30/2006
Federal Report of Completed Projects	**Construction Begin Date**	**Time Charges Stop Date**
	2/14/2006	2/28/2006

Initially, the study periods were identified as three calendar years before and three calendar years after the year in which construction occurred. This would allow a buffer zone of several months before and after the construction time periods in order to compensate for any abnormal change in driving patterns due to motorist unfamiliarity with lingering construction equipment, road closures, and newly implemented centerline rumble strips.

However, the study periods were scaled back due to limitations of the crash data. Instead of analyzing three calendar years before and after the construction period, two calendar years before and after the construction period were analyzed. The final dates for the preliminary before-after analyses were:

- Before period: January 1, 2003 to December 31, 2004
- After period: January 1, 2007 to December 31, 2008

The last attribute to be determined were the precise study locations. This was accomplished through the use of variables within GDOT's crash database. Though preliminary milepost information was obtained for each centerline rumble strips installation site, differences in conventions used in delineating mileposts from the crash database to the Project Plan Sheets made it unclear to what point of the road a given milepost information referred. Because of this, correct crash data could not be confidently geographically matched to the roadways where there were centerline rumble strips. The methodology used in this study to verify milepost locations is discussed in Chapter 4.2.2.

.

4.2 Crash Database

To analyze the safety effectiveness of centerline rumble strips sites throughout Georgia, crash data was required for the periods before centerline rumble strips installation and after centerline rumble strips installation. The crash data used in this study were annual crash data files obtained from GDOT. This overall crash database included information for every reported crash in the state of Georgia from 2000 to 2009 and its characteristics. A list of these characteristics can be found in Appendix C.

4.2.1 Definitions of Essential Variables

Prior to working with the crash data, crashes for the entire state of Georgia from 2000 to 2009 were separated by years and sanitized of any personally identifiable information. For every year, characteristics for each crash report were subdivided into multiple tables, each containing a different set of attributes for the crash. For this study, only location and accident information were studied. The variables used from the Location table were: Accident ID, Accident Date, RCLINK, Milelog (referred to as Milepost in the rest of this document), Intersecting Road Type, AADT, Dividing Highway Barrier Type, Dividing Highway Median Type, and Functional Classification. The variables used from the Accident table were: Accident Time, Number of Vehicles, Number of Fatalities, Number of Injuries, and Manner of Collision. The definitions of these variables are explained in the following sections.

Accident ID

Accident ID is a variable from each table; it is also named LOC_ACC_ID. It is an eight-digit number unique to each crash entry and police report; in other tables it is known as the Microfilm number. The first digit refers to the year of the incident (e.g., the crash with the Accident ID 7000000 occurred in 2007), while the rest of the digits represent an automatically generated increment counter. This variable was the same across all tables, allowing the Location and Accident tables to be linked for this study.

Accident Date

Accident date, also known as LOC_ACC_JULDT in the Location table, is the date on which the crash occurred. This was used to filter the crashes into study periods for comparison and analysis.

RCLINK

Every roadway in Georgia is assigned a unique number, known as the RCLINK. The RCLINK is a 10-digit identification number that defines the county the road is located in, the route type, the route number, and a two digit suffix. Table 13 shows the breakdown of the RCLINK identification number, while Table 14 shows the GDOT county codes of the counties where centerline rumble strips have been installed. The county codes are based on the Federal Information Processing Standard (FIPS) sequence.

Table 13: RCLINK Information

Variable	Description
1234567890	Three digit county code, complying with the Federal Information Processing Standard (FIPS) sequence
123**4**567890	One digit route type identifier 1 – State Route 2 – County Route 3 – City Street 4 – Public Road
1234**5678**90	Up to four digit route number with leading zeros
12345678**90**	Two digit suffix 00 – Default suffix BU – Business route SR – Spur route

Table 14: GDOT County Codes for Counties with Centerline Rumble Strips

County ID	County Name	County ID	County Name
035	Butts	129	Gordon
045	Carroll	151	Henry
051	Chatham	171	Lamar
077	Coweta	213	Murray
117	Forsyth	227	Pickens
123	Gilmer	293	Upson

Milelog

Milelog is a variable that indicates the milepost (MP) of the roadway where each crash occurred. Also known as LOC_ACC_MILELOG in the Location table, the mileposts are measured in increasing fashion from south to north or west to east, resetting to zero at the beginning of each RCLINK. The crash attributes information originated from the initial police report filed at the time of the crash which did not contain a milepost. Instead, the report contained fields describing a general location of the crash to be inputted relative to the nearest intersection. This distance could range from 250 feet to several miles. It is from this description that the milepost was assigned to the crash entry in the database.

AADT

Each crash in the crash database had an associated AADT variable, or LOC_AADT_COUNT in the Location table, that contained the AADT value of the roadway segment at the time of the crash. These values were not used, however, as the AADT values did not always correspond to the AADT values from GDOT's STARS database. Instead, AADT values from the roadway database were used for this study.

Divided Highway Barrier Type

The divided highway barrier type, or LOC_DIVHWYBARRIER_TYPE in the Location table, contained information regarding the barrier type of the roadway at each crash location. The barrier types are listed in Table 15.

Table 15: Divided Highway Barrier Classifications

Variable	Description
Divided Highway Barrier Type	0 – No Barrier 1 – Curb 2 – Guardrail 3 – Curb and Guardrail 4 – Fence 5 – New Jersey Concrete Barrier 6 – Cable 7 – Other

The majority of the crashes on roadways with centerline rumble strips in this study were located on roadways with no barrier. All of the roadways used as reference sites were located on roadways that did not have a barrier.

Divided Highway Median Type

The divided highway median type, or LOC_DIVHWYMEDIAN_TYPE in the Location table, contained information regarding the median type of the roadway at each crash location. The median types are listed in Table 16.

Table 16: Divided Highway Median Classifications

Variable	Description
Divided Highway Median Type	0 – Undivided Road 1 – Grass 2 – Soil, Stone 3 – Park, Business 4 – Couplet 5 – Concrete 6 – Other 7 – Roadway Separated by Barrier Only

The majority of the crashes on roadways with centerline rumble strips in this study were located on roadways that were undivided. All of the roadways used as reference sites were located on roadways that were undivided.

Functional Classification

Each crash in the crash database was assigned a Functional Classification, or LOC_FUNCTIONALCLASS_TYPE, in the Location table. This variable described the road on which the crash occurred and assisted in determining whether the crash was in a rural or urban area. The functional classifications are listed in Table 17.

Table 17: Functional Classification Classifications

Variable	Description
Functional Classification	1 – Rural – Interstate Principal Arterial 2 – Rural – Principal Arterial 6 – Rural – Minor Arterial 7 – Rural – Major Collector 8 – Rural – NFA Minor Collector 9 – Rural – Local 11 – Urban – Interstate Principal Arterial 12 – Urban – Freeway and Expressway 14 – Urban – Principal Arterial 16 – Urban – Minor Arterial Street 17 – Urban – Collector Street 19 – Urban – Local

Number of Fatalities

The number of fatalities, or ACC_TNF in the Accident table, tallied the number of fatalities in each crash. For this study, the number of fatalities variable was used to determine the presence of fatalities rather than the number of fatalities in each crash.

Number of Injuries

The number of injuries, or ACC_TNI in the Accident table, tallied the number of injuries in each crash. For this study, the number of injuries variable was used to determine the presence of injuries rather than the number of fatalities in each crash.

Manner of Collision

The manner of collision, or ACC_MNRC_TYPE in the Accident table, contained information regarding the manner of collision as deemed appropriate by the police officer filing the police report. For this study, two manners of collisions (crash types) were investigated: head-on collisions and opposite-direction sideswipe collisions. These crash types typically involve crossing the centerline and are the crash types that centerline rumble strips seek to mitigate. Table 18 lists the different manners of collision.

Table 18: Manner of Collision Classifications

Variable	Description
Manner of Collision	1 – Angle 2 – Head-On 3 – Rear End 4 – Sideswipe-Same Direction 5 – Sideswipe-Opposite Direction 6 – Not a Collision With a Motor Vehicle

Of the aforementioned variables, milepost, and manner of collision may exhibit bias as these values were based on the reporting police officer's discretion. It was assumed that with sufficient crashes, the variability of bias from these variables would be similar across any sample sizes.

4.2.2 Location Verification of Installation Sites

Once the list of study sites was determined, the characteristics of these sites' roadways, most notably the locations of where centerline rumble strips were installed along the study sites, needed to be verified. This was accomplished through cross-checking the mileposts provided from the GDOT Project Plan Sheets and the crash database, which contained location information for each roadway.

Though the beginning and ending mileposts of each centerline rumble strips site were explicitly mentioned in the Project Plan Sheets, it was discovered that the majority of the mileposts did not agree with the mileposts specified in TransPI. In order to verify the exact mile posts of centerline rumble strips, each crash from the crash database within the milepost range specified in the Project Plan Sheet was plotted onto Google Earth and verified using Google Street View. A general assumption was made that the mileposts of each crash in the crash database was correct. The following attributes of each crash entry were examined:

- RCLINK
- Beginning milepost of the installation site
- Ending milepost of the installation site
- X-coordinate of each crash
- Y-coordinate of each crash

In Microsoft Access, a SQL query was run to filter for the crashes that occurred on the roadways with centerline rumble strips by RCLINK, beginning and ending mileposts. The result was a listing of every crash that occurred on each of the 10 sites within the beginning and ending mileposts as provided by the Project Plan Sheets. Each crash entry contained the RCLINK (the road it occurred on), the MP of occurrence, and an X-Y coordinate. These values were then converted into comma-separated values (CSV) files in the format of "MP,Coordinates". This was in turn converted into a keyhole markup language (KML) file through the use of an online website before finally being plotted into Google Earth (Figure 22) [24].

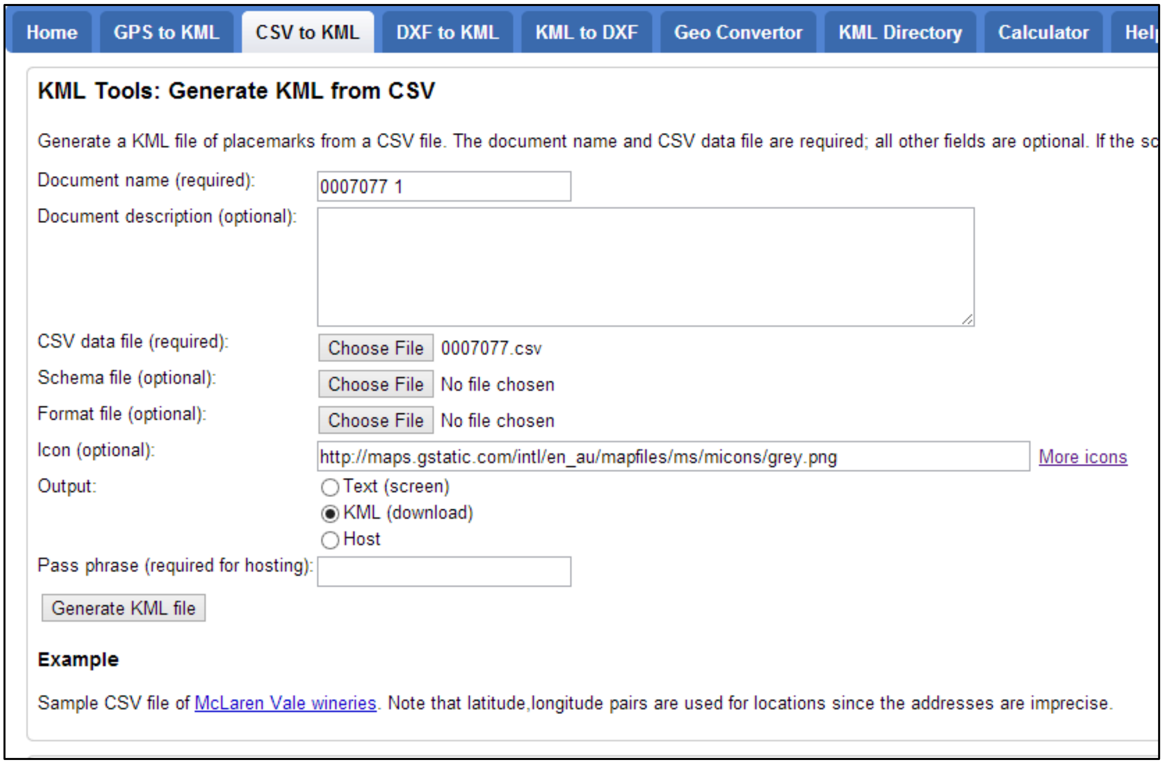


Figure 22: Screenshot of CSV to KML Website [24]

In Google Earth, each crash was represented with a white pin, which was then examined along with Google Street View to verify the true beginning and ending mileposts of each site. Figure 22 highlights the beginning and ending regions of Project No. 0007077, respectively.

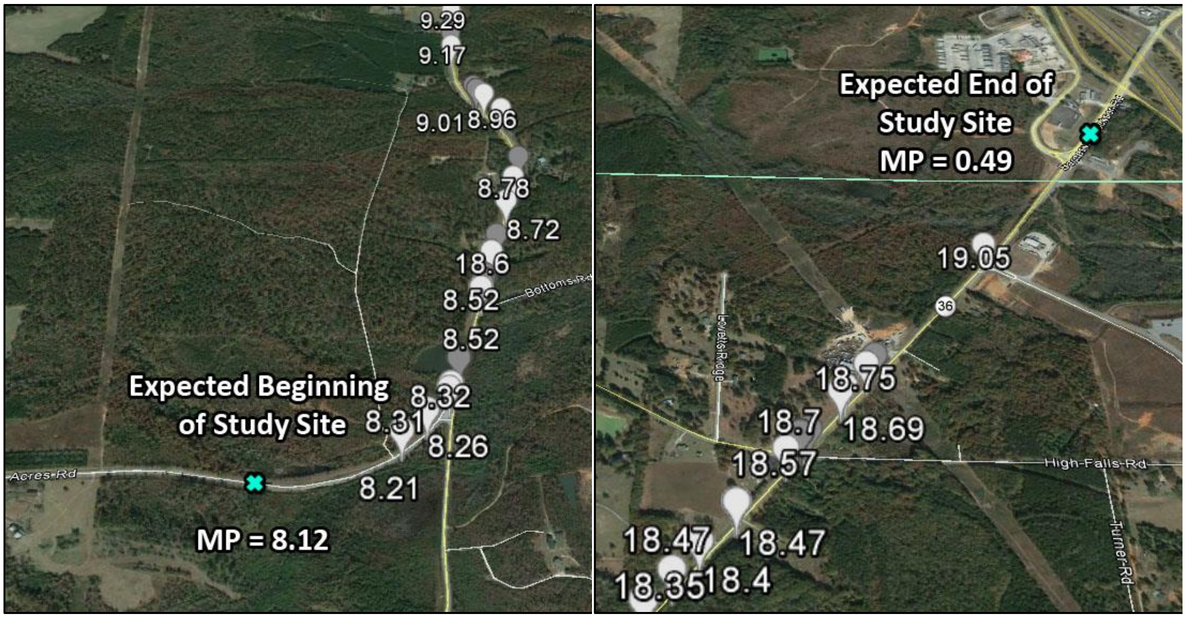


Figure 23: Expected Beginning (left) and Ending (right) of Study Site Example [13]

From these maps, a reference point for the mileposts of the roadways could be established. Next, Google Street View was used to determine the actual beginning and ending mileposts of the centerline rumble strips by entering Google Street View mode and continuing along the roadway away from the beginning and ending MP until centerline rumble strips could no longer be seen. This process is shown in Figure 24 in which Google Street View was used to move west of MP 8.12 until centerline rumble strips terminated. As can be seen here, the end of the area with centerline rumble strips was closer to the intersection than as indicated by the Project Plan Sheet.

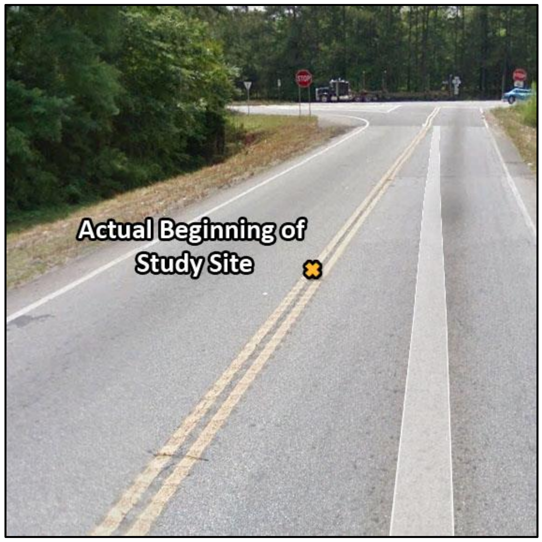


Figure 24: Actual Beginning of Study Site for Roadway Verification [15]

The distance from the expected beginning milepost to the actual beginning milepost was then calculated using the Ruler tool in Google Earth, plotting a path along the centerline of the roadway. This process is shown in Figure 25, and was repeated to determine the actual ending milepost.

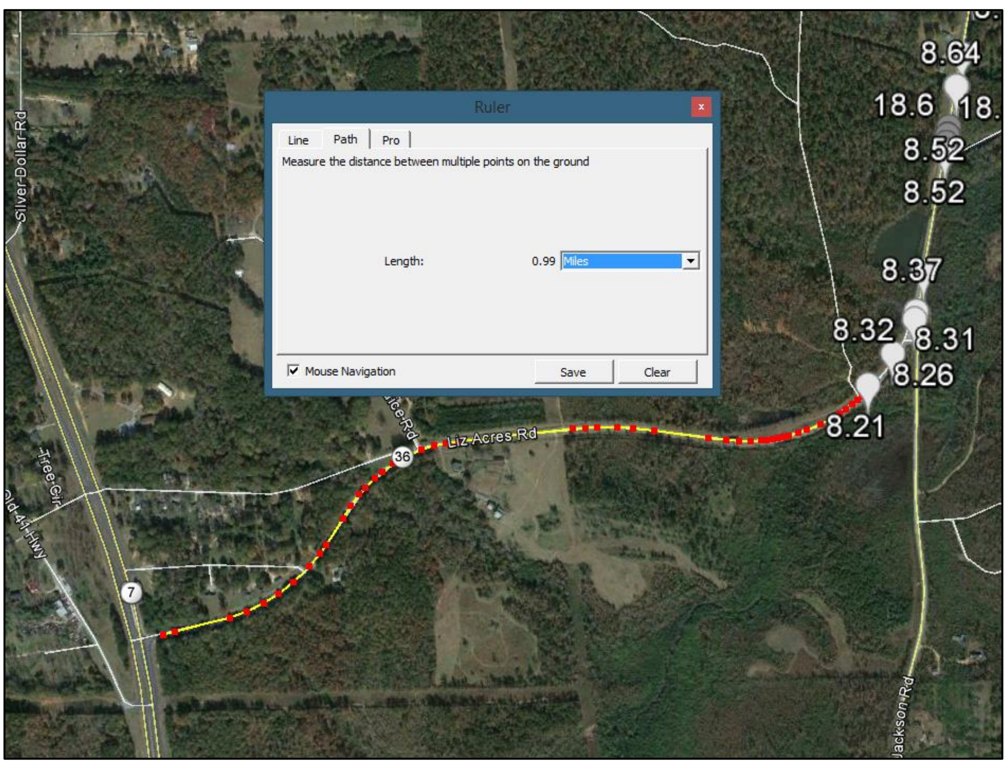


Figure 25: Determination of the MP of the Actual Beginning of Each Site [13]

For example, the actual beginning milepost of Project No. 0007077 was found to be at MP 7.21 rather than MP 8.12; the actual ending milepost was found to be at MP 19.05 in the same county rather than MP 0.49 in the next county. This process was repeated for each of the 10 study sites.

4.2.3 Crash Data Aggregation

Once the beginning and ending mileposts were determined for every study site, the overall crash database was divided into two databases:

- Treatment crashes – crashes that occurred on the study sites
- Reference crashes – crashes that occurred on roadways with similar characteristics to those of the study sites

The latter table was created based on statistics of the roadways with centerline rumble strips.

In order to provide a thorough comparison, only crashes that met the criteria listed in Table 20 were compared to the crashes that occurred on roadways with centerline rumble strips. In this manner, crashes in the reference crash database were compared to crashes in the treatment crash database. Among the 10 study sites, the centerline rumble strips were installed in intervals of one to five months as seen in Figure 26.

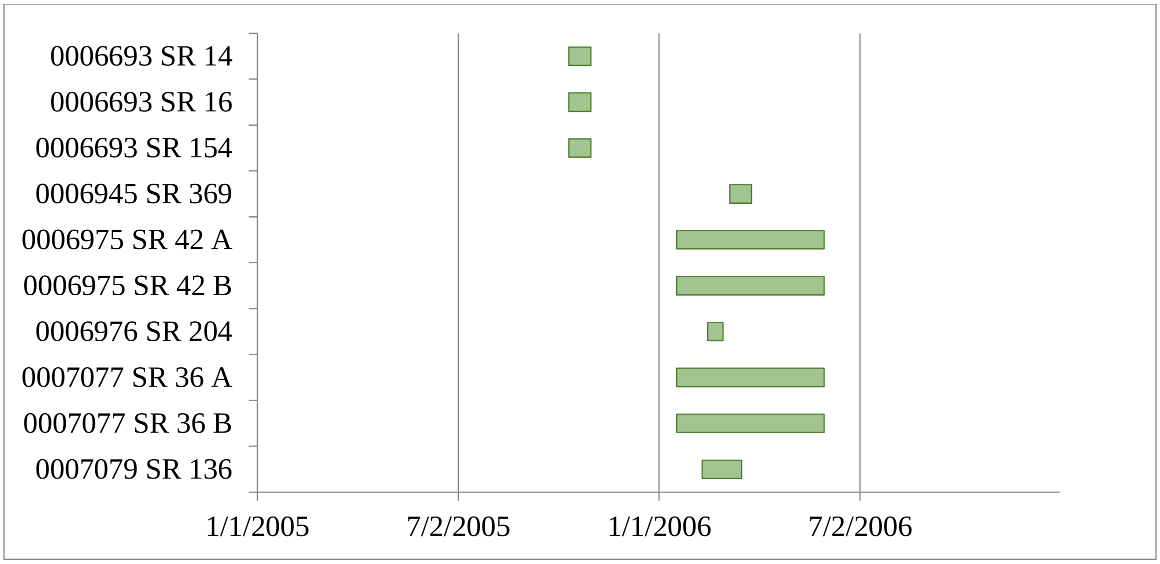


Figure 26: Construction Periods for the 10 Installation Sites

Because some sites' centerline rumble strips were completed within 2005, and other sites' centerline rumble strips were completed within 2006, the before and after periods were chosen in order to simplify the comparison of all sites at once. Furthermore, by analyzing the same time periods (i.e., two calendar years before and two calendar years after the years of construction), the study periods would enable a comparison where no months are over-represented.

4.2.3.1 Treatment Crash Database

Upon confirmation of the sites' beginning and ending mileposts, the overall crash database could then be filtered to produce a new treatment crash database that only contained crashes that occurred on the roadways where centerline rumble strips were installed. This was accomplished through the use of a SQL code that used the RCLINKs of the installation sites and the dates of the study period to retrieve these crashes. Two tables were created within the treatment sites database: crashes that occurred in the before period and crashes that occurred in the after period. Once the crashes were pooled, statistics regarding the roadways in the treatment sites database were evaluated in order to create the reference crash database. Several variables from the treatment crash database, listed in Table 19, were analyzed to create the reference crash database.

Table 19: Roadway Variables Used to Create the Reference Crashes Database

Variable
Dividing Highway Barrier Type
Dividing Highway Median Type
Functional Classification
Number of Left Lanes
Number of Right Lanes

These roadway characteristics of the treatment sites crash data were then used as an indicator of the physical characteristics required for crashes of the reference crashes.

4.2.3.2 Reference Crashes Database

Based on the roadway characteristics of the treatment crashes, filters were applied to the overall crash database to obtain a reference crash database, which consisted of crashes on roadways with similar physical characteristics to the crashes of the treatment crashes. The filters applied are listed in Table 20.

Table 20: Filters Used to Create the Comparison Crashes Database

Variable	Filter
Accident Date	Same dates as the crashes in the treatment crashes database
Dividing Highway Barrier Type	0 – No Barrier
Dividing Highway Median Type	0 – Undivided Road
Functional Classification	2 – Rural – Principal Arterial 6 – Rural – Minor Arterial 7 – Rural – Major Collector
Number of Left Lanes	1 – 1 lane on the left side of the roadway
Number of Right Lanes	1 – 1 lane on the right side of the roadway

The reference crash database excluded the crashes present on the treatment crashes database. For the analyses described in Chapter 4.3, this was accomplished using the Find Unmatched Query Wizard function in Microsoft Access. For the analysis described in Chapter 4.4, a Perl script was written to accomplish this.

4.3 Preliminary Before-After Analyses

Upon completion of the data collection, the next step was to analyze the crashes. In this study, before-after analyses were conducted according to total crashes, crash severity, and crash types. Each area of interest was broken down into sub-categories detailed in Table 21 and Table 22.

Table 21: Analysis of Total Crashes

Area of Interest	Description
Total	All Crashes
Crash Severity	Injuries
	Fatalities
Crash Type	Head-on
	Opposite-Direction Sideswipe
	Not a Collision with a Motor Vehicle

Table 22: Analysis of Specific Crash Types

Area of Interest	Description
Head-on	Total
	Injuries
	Fatalities
Opposite-Direction Sideswipe	Total
	Injuries
	Fatalities

In this study, because the number of crashes was counted, the counts for injuries refer to the number of crashes that involved injuries. In this manner, a crash labeled as injuries may involve both injuries and non-injuries. Similarly, a crash labeled as injuries may involve both injuries and fatalities. As long as there were injuries in the crash, it was counted as an injury crash.

As centerline rumble strips seek to mitigate cross-over crashes, the difference between the multitude of crashes in the before and after periods for categories such as head-on crashes and opposite-direction sideswipe crashes enables determination of its safety effectiveness. In addition, though the crash type "not a collision with a motor vehicle" encompasses a variety of crashes, it is important to examine as it includes crashes involving a single vehicle that may encroach upon or cross over the centerline; all other crash types as classified by GDOT involve two or more vehicles [12]. The definitions of these crash types are ascertained from GDOT's Uniform Accident Reporting Guide. Below is the definition for head-on crashes.

> A collision in which the front-end of one vehicle collides with the frontend of another, while the two vehicles are traveling in opposite directions. All accidents in which the front of both vehicles makes contact in the First Harmful Event are head on. Direction of force will NOT be used in determining head-on collisions.

Below is the definition for opposite-direction sideswipe crashes.

> Applies when the first injury or damage-producing event involves two motor vehicles colliding side to side from generally considered opposite directions.

Lastly, below is the definition for crashes that are classified "not a collision with a motor vehicle." Once again, it is important to note that this category includes all crashes that involve only a single vehicle not limited to the examples listed in the definition.

> Applies when the first occurrence doing injury or damage involves a motor vehicle that does not involve a collision, overturning, or pedestrian. These include:
>
> - Accidental poisoning from carbon monoxide generated by the motor vehicle in transport.

- Breakage of any part of the motor vehicle while in transport which results in further property damage or injury.
- Note: Any mechanical failure such as a tire blowout, broken fan belt, etc., does not, by itself constitute a motor vehicle accident. However, any subsequent injury or damage resulting from the mechanical failure would be a motor vehicle accident if the motor vehicle were in transport.
- Any other injury or damage-producing event involving only the motor vehicle that is of a non-collision nature, such as a motor vehicle striking holes or bumps in the surfaces of the roadway

4.3.1 Direct Before-After Analysis

The first type of analysis conducted was the direct before-after analysis. Also known as the naïve before-after analysis, the direct before-after analysis offered an initial indication about the effectiveness centerline rumble strips. In this analysis, only crashes on roadways with centerline rumble strips, treatment crashes, were examined. The number of crashes before installation and after installation at each site for each of the categories of Table 21 and Table 22 were compared to each other. If there was a decrease in the number of crashes, this could be a potential indicator that centerline rumble strips were effective for that particular area of interest. However, as with any naïve before-after analysis caution must be exercised in the interpretation of the results as the findings are subject to selection bias, regression-to-the-mean, and factors other than the treatment, such as weather, different driving populations, incident reporting changes, etc.

4.3.2 Comparison Before-After Analysis

Though the direct before-after analysis offered a good starting point for determining the safety effectiveness of centerline rumble strips, it introduced errors associated with selection bias and regression-to-the-mean as stated above. To begin addressing these issues, the change in the number of crashes in the treatment crashes database for each of the categories in Table 21 and Table 22 were compared with the change in the number of crashes in the reference crashes database. If the crash frequency reductions in the before and after periods for the treatment crashes were greater than that of the reference crashes of the same time period, this provides further indication that the centerline rumble strips may be effective for that particular area of interest. While regression-to-the-mean and selection bias remain an issue with this approach, and thus results must be viewed cautiously, general trends in accident rates, weather influences, incident reporting changes, etc. are at least partially reflected.

4.4 Comparative Analysis

The third type of analysis conducted is a simple comparative analysis. As discussed in the literature review, the empirical Bayes method allows the inclusion of factors that may influence the crash rates, such as traffic volume for a particular roadway length, the width of the shoulder, the number of lanes, or the time of day. Taking these factors into account, the empirical Bayes method allows the prediction of what the crash rate would have been on a treated section if the treatment were not applied. In this study, the traditional methodology of the empirical Bayes before-after method was reduced to a simple comparative analysis of the safety performance function (SPF). The following sections describe the methodology of this analysis.

4.4.1 Safety Performance Functions

The traditional empirical Bayes analysis allows for the estimation of the crash rate on the treated site as if the treatment were not applied through a function called the safety performance function (SPF). SPFs are regression models that estimate the crash frequency on a roadway segment and are developed using observed crash data from reference sites with similar roadway characteristics. These characteristics include roadway geometry (e.g., shoulder widths, lane widths, presence of horizontal curves), travel behavior (e.g., time of day, day of the week), or traffic volume. There are two types of SPFs, Type I and Type II, which are described in the literature review. This analysis will focus on the Type I SPF; a functional form of this SPF is given in Equation 1.

$$\boldsymbol{\mu_i = SL_i * e^{\alpha} * (AADT_i)^{\beta}} \qquad (1)$$

Where:

μ_i =	Crash frequency of roadway section i
SL_i =	Segment length of roadway section i
$AADT_i$ =	AADT of roadway section i
α, β =	Regression parameters

Equation 1 represents a very simple risk/exposure formulation for the SPF. In this formulation, the product of Segment Length and AADT (i.e., segment VMT) provides the exposure and the regression parameters that are used to define the risk. The alpha coefficient supplies the "base" risk associated with the location, geometry, driver population, etc. for the conditions present while the beta coefficient corrects for the nonlinearity of risk associated with AADT. This latter non-linearity arises since many crashes are associated with multiple vehicles and thus the probability of a crash is dependent on the probability that other vehicles are present. Traditionally, the crash frequency per roadway segment i with length SL_i and traffic volume $AADT_i$ are aggregated for all reference roadways. In turn, these data are fitted to the functional form (typically a negative, or overdispersed, binomial distribution) to determine the regression parameters. Once the regression coefficients are identified, the crashes per year on a study site can be predicted using the developed function. In this study, only 2007 roadway characteristics and traffic volumes were available. Thus, only the Type I SPF could be developed. However, instead of developing a function based on the aggregate of all AADTs, segment lengths, and crash counts of a reference site, the approach taken in this study examined small AADT ranges on the scale of 1000 vehicles-per-day (vpd) to allow evaluation of the alpha (risk modifying) coefficients independently of the exposure variables. From this, a crash modification factor was developed for each AADT range and the safety effectiveness of centerline rumble strips for that particular AADT range was determined. While a straightforward method for evaluating the impacts of centerline rumble strips on safety, this approach still makes the critical assumption that treatment sites have, on average, the same base crash rate corrected for known risk factors (e.g., two-lane vs. four lane road, urban vs. rural settings, etc.) as the reference sites including the impact of any selection bias or regression-to-the-mean from the selection of treatment sites.

4.4.2 Background of the Methodology

Type I SPFs have already been developed for several regions of the nation. At the time of this study, the FHWA program *SafetyAnalyst* has also used Type I SPFs safety [1]. However, the SPFs developed in other regions as well as *SafetyAnalyst* used crash data and roadway data from the northeast to derive their regression parameters. Because of this, the developed SPFs may not be applicable to roadways and driving behavior of states in the South, including Georgia where conditions may be significantly different. Therefore, the fundamentals of the SPF were examined and an alternative to the empirical Bayesian analysis was established.

Fundamentally, the concept of the SPF relates the crash events to the exposure and risk as seen in Equation 2.

$$Crash\ Events = Exposure * Risk\ Factor \qquad (2)$$

Essentially, the potential for a crash event to occur is a function of how much one is exposed to a risk. Equation 3 translates this concept to the Type I SPF.

$$Crash\ Frequency = VMT * Risk\ Factor \quad (3)$$

Here, vehicle-miles traveled (VMT) represents the exposure, and the risk factor represents the risk deviating from some base condition that a motorist encounters while traveling. This could represent a change that increases the risk, such as a decrease in lane width or the presence of a horizontal curve, or a change that decreases the risk, such as an increase in shoulder width or the addition of roadway lighting. In this study, the risk factor evaluated was the presence of centerline rumble strips. In this manner, if the crash frequency is lower for the treated sites that have centerline rumble strips than for the reference sites that do not have centerline rumble strips, then it can be concluded that centerline rumble strips are an effective countermeasure provided other factors (e.g. no selection bias or regression-to-the-mean, similar geometry, driver populations, etc.) are equivalent.

However, instead of developing a full SPF equation, the effectiveness was determined by comparing the number of crashes per VMT of the treated roadways with the number of crashes per VMT of the reference roadways to produce a crash modification factor (CMF). A crash modification factor was used to compute the expected crash frequency after implementing a given countermeasure at a specific site. This was possible by rearranging the functional form of the type I SPF to match the concept in Equation 1, where the crash frequency is a function of exposure to the risk. If AADT is moved to combine with the segment length (achieved by reducing the β parameter by one, we have an alternate expression of the SPF that we illustrate in Equation 4.

$$\mu_i = (SL_i * AADT_i) * (e^{\alpha} * AADT^{\beta-1}) \quad (4)$$

Vehicle-miles-traveled (VMT) is a product of the roadway length and the traffic volume of a particular roadway. The unit of roadway length is miles and the unit of the AADT is vehicles per day; therefore the units of the VMT is miles·vehicles per day, or the total miles traveled by all vehicles on a roadway segment in one day. Substituting the variables of Equation 4 with Equations 5 and 6 leads to Equation 7, which matches the concept of the Type I SPF from Equation 3.

$$VMT_i = (SL_i * AADT_i) \tag{5}$$

$$Risk = (e^{\alpha} * AADT^{\beta-1}) \tag{6}$$

$$\mu_i = VMT_i * Risk \tag{7}$$

To obtain the VMT, the crashes in both the treatment sites and the reference sites needed to be joined to their respective roadways where each crash occurred.

4.4.3 Combining Crash Data and Roadway Data

The roadway database used in this study described all the roadways in the state of Georgia. Each roadway was divided into smaller segments, first by RCLINK and then by characteristics. As mentioned in Chapter 4.2.1, RCLINK is a unique 10-digit number assigned to a roadway that defines the county the road is located in, the route type, and the route number. From this definition, each RCLINK represented a roadway that could be 0.10-miles in length or dozens of miles in length. Each RCLINK is then subdivided into homogeneous roadway subsections in which the characteristics of the road remained the same throughout the entire subsection. A complete list of the characteristics detailed in the roadway database is listed in Appendix C.

For this analysis, the main variable needed is the VMT for each roadway subsection. In order to obtain this, the overall roadway database was divided into two databases:

- Treatment roadways
- Reference roadways

The treatment roadways contained all of the roadways with centerline rumble strips. The reference roadways contained all of the roadways with similar physical characteristics to those of the treatment roadways. This latter correction was to ensure that known risk modifying factors (e.g. divided vs. undivided road) were held constant in the selection. Geometric risk modifying factors (e.g. horizontal and vertical curves) were assumed to average out between treated and reference segments and were not explicitly considered. It should be noted that systematic differences in these or other factors between the treatment and reference segments could produce differences in risk that could be incorrectly interpreted as being associated with the presence of the centerline rumble strips. The variables used to obtain the reference roadways are listed in Table 23.

Table 23: Reference Roadway Database

Variable	Description
RCLINK	Fourth digit = 1 (State Route)
Highway Barrier Type	0 – No Barrier
Highway Median Type	0 – Undivided Road
Functional Classification	2 – Rural – Principal Arterial 6 – Rural – Minor Arterial 7 – Rural – Major Collector
Number of Left Lanes	1 – 1 lane on the left side of the roadway
Number of Right Lanes	1 – 1 lane on the right side of the roadway
Excluding	Roadway segments of the Treatment Roadway

For every roadway segment in both the treatment roadways and the reference roadways, the number of crashes from the treatment sites and the reference sites were aggregated, respectively. Figure 27 shows a screenshot of this combined database.

	B	C	L	M	AJ	AS	AT	BG	BJ	BK	BL	BU	BY	BZ	CA
1	RCLINK	BEG_MEASURE	DIV_HWY_BARRIER_TYPE	DIV_HWY_MEDIAN_TYPE	ROUTE_TYPE	T_LANES_LEFT	T_LANES_RIGHT	END_MEASURE	SECTION_LENGTH	TOTAL_LANES	AADT	FUNC_CLASS	Total Crashes	Injury Crashes	Fatal Crashes
2	351004200	7	0	0	1	1	1	7.1	0.1	2	5460	6	0	0	0
3	351004200	6.04	0	0	1	1	1	6.12	0.08	2	5460	6	0	0	0
4	351004200	7.7	0	0	1	1	1	7.71	0.01	2	8130	6	0	0	0
5	351004200	1.91	0	0	1	1	1	1.95	0.04	2	1190	7	0	0	0
6	351004200	7.54	0	0	1	1	1	7.7	0.16	2	8130	6	2	1	0
7	351004200	6.75	0	0	1	1	1	6.78	0.03	2	5460	6	0	0	0
8	351004200	4.75	0	1	1	1	1	4.85	0.1	2	2640	7	0	0	0
9	351004200	5.05	0	1	1	1	1	5.07	0.02	2	5460	6	0	0	0
10	351004200	4.42	0	0	1	1	1	4.53	0.11	2	2640	7	0	0	0
11	351004200	3.03	0	0	1	1	1	3.05	0.02	2	2640	7	1	1	0
12	351004200	1.95	0	0	1	1	1	1.97	0.02	2	1190	7	0	0	0
13	351004200	5.11	0	1	1	1	1	5.13	0.02	2	5460	6	0	0	0
14	351004200	3.31	0	0	1	1	1	3.34	0.03	2	2640	7	0	0	0
15	351004200	7.97	0	0	1	1	1	7.99	0.02	2	8130	6	0	0	0
16	351004200	3.4	0	0	1	1	1	3.55	0.15	2	2640	7	1	0	0

Figure 27: Combined Roadway and Crashes Database

Once the treatment roadways were joined with the treatment sites, and the reference roadways and the reference sites were joined, the crash frequencies per VMT could be averaged, which then determined the crash modification factor.

4.4.4 Crash Modification Factor (CMF)

The crash modification factor, or CMF, quantifies the change in expected average crash frequency at a site due to the implementation of a treatment and allows the potential change in expected crash frequency or crash severity to be estimated (HSM). The application of the CMF involves evaluating expected average crash frequency with or without a particular treatment, or estimating it with one treatment versus a different treatment. In this study, the CMF is determined by taking the ratio of the crash frequency per VMT of treated sites to the crash frequency per VMT of the reference sites. If the CMF is below 1.0, then it can be said that centerline rumble strips were an effective countermeasure in Georgia with the same cautions as mentioned previously regarding selection bias, etc. First, the risk needed to be determined; this is reiterated in Equation 8.

$$Risk = (e^{\alpha} * AADT^{\beta-1}) \quad (8)$$

Where:

e^{α} =	Risk associated to factors other than the AADT
$AADT^{\beta-1}$ =	Risk associated to AADT
α, β =	Regression parameters

The risk associated to other factors, e^{α}, can be rewritten to account for other factors, as shown in Equation 9.

$$e^{\alpha} = e^{CLRS+\alpha_1+\alpha_2+\alpha_3+\cdots+\alpha_n} = e^{CLRS} * e^{\alpha_1} * e^{\alpha_2} * e^{\alpha_3} * \ldots * e^{\alpha_n} \quad (9)$$

Where:

e^{α} =	Risk associated to factors other than the AADT
e^{CLRS} =	Risk attributed to centerline rumble strips
$e^{\alpha 1}$, $e^{\alpha 2}$, $e^{\alpha 3}$, … … $e^{\alpha n}$	Risk attributed to other factors such as lane width, presence of horizontal curves, shoulder width, etc…

The rewriting of other factors allows the CMF to be determined with this methodology as it assumes that with a sufficient amount of roadway miles, e^{α} for both the treated sites and the reference sites are the same with the exception of e^{CLRS}. Putting Equation 9 into Equation 4 leads to Equation 10.

$$\mu_i = (SL_i * AADT_i) * [(e^{CLRS} * e^{\alpha_1} * e^{\alpha_2} * e^{\alpha_3} * \ldots * e^{\alpha_n}) * AADT^{\beta-1}] \quad (10)$$

$$\frac{\mu_i}{(SL_i * AADT_i)} = (e^{CLRS} * e^{\alpha_1} * e^{\alpha_2} * e^{\alpha_3} * \ldots * e^{\alpha_n}) * AADT^{\beta-1}$$

An examination of Equation 10 reveals a potential method for evaluation of the safety impacts of centerline rumble strips. Since the number of potential reference sites is large, the impact of the beta (volume dependent) coefficient can be eliminated by selecting only reference sites with AADTs very close to those at the treatment sites to be evaluated. For a fixed or nearly fixed value of AADT, the last term in Equation 10 is essentially a constant. By averaging the observed crash rate (left hand side of Equation 11) at reference sites with the same physical characteristics (other alpha coefficients) and AADT at treatment sites and taking the ratio with the observed crash rate at treatment sites, the right hand side of the equation reduces to the crash modification factor for the treatment sites. This is illustrated in Equation 11. Here, i represents the set of roadway sections with the same or similar AADT levels.

$$\frac{\sum_1^i \frac{\mu_i}{(SL_i * AADT_i)}_{treated}}{\sum_1^i \frac{\mu_i}{(SL_i * AADT_i)}_{reference}} = \frac{(e^{CLRS} * e^{\alpha_1} * e^{\alpha_2} * e^{\alpha_3} * \ldots * e^{\alpha_n}) * AADT^{\beta-1}}{(e^{\alpha_1} * e^{\alpha_2} * e^{\alpha_3} * \ldots * e^{\alpha_n}) * AADT^{\beta-1}}$$

$$= e^{CLRS} = CMF \tag{11}$$

For only e^{CLRS} to remain and for a fair comparison of segments with similar traffic volumes to be conducted, the term $AADT^{\beta-1}$ for the treated sites needs to be as close as possible to that of the reference sites. This is made possible by examining small ranges of AADT, referred to as bins in this thesis. As the AADT bins become sufficiently small, the variation in AADTs of the roadway segments on which these crashes occurred also becomes sufficiently small. In this way, the hope is that the traffic volume characteristics between the treatment roadway segments and the reference roadway segments are similar and that other factors can be eliminated. In this study, the bins evaluated were segments with AADT increments of 500, 1,000, 2,000, and one that roughly approximates a logarithmic function, which is shown in Table 24.

Table 24: AADT Bins of Logarithmic Approximation for the Empirical Bayes Analysis

AADT Bins of "Log" (vpd)
2000 to 3499
3500 to 4999
5000 to 6999
7000 to 9999
10000 to 13999
14000 to 19999
20000+

In addition to calculating the CMFs for the after years, CMFs were derived for each of the AADT bins for all years 2003 through 2008 to investigate any potential secular trends that may exist. CMFs were then plotted for crashes of all types and injury severities and the safety effectiveness of centerline rumble strips was examined.

CHAPTER 5

RESULTS

This results chapter presents the results and discusses the safety effectiveness of centerline rumble strips. The first section discusses the databases used for this study. The following sections detail the results of each of the three analyses conducted.

5.1 Crash Statistics

5.1.1 Roadway Characteristics of Treatment Sites

For this study, 10 sites of centerline rumble strips were examined, yielding a total of 3,497 crashes over a period of four years: 1,829 crashes in the before period and 1,668 crashes in the after period. After a thorough verification process regarding the locations of these sites, the installation sites were analyzed individually and as a whole. Throughout the state of Georgia, approximately 126 miles of roadway with centerline rumble strips were analyzed in this study, representing different geographical environments and traffic volumes. As seen in Figure 28, over 85% of the treatment sites' roadway miles were classified as rural.

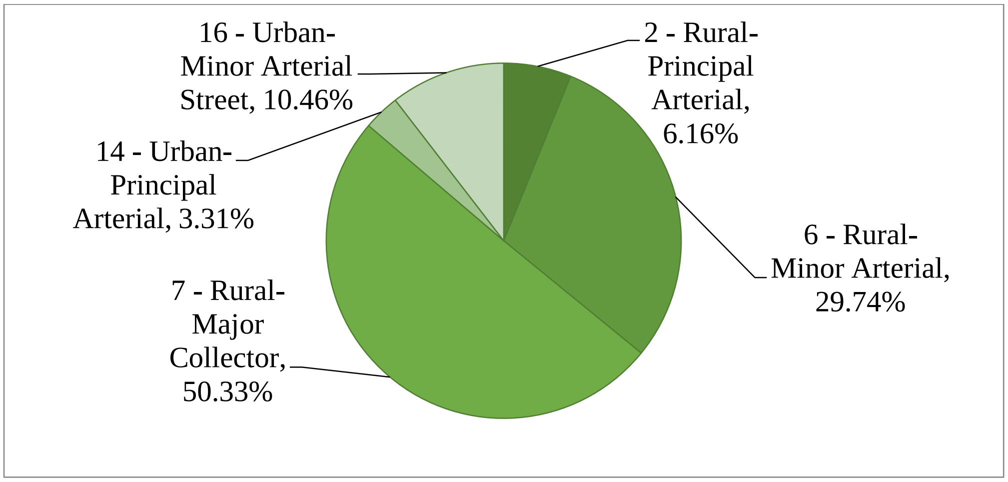


Figure 28: Functional Classifications of the Treatment Roadways

100% of the study sites' roadway miles were classified as Georgia State Routes, 99.95% were roadways without a barrier, and 97.30% were roadways without a median. Lastly, 97.60% of the study sites' roadway miles had one left lane, and 97.60% had one right lane. These characteristics were used to establish the reference sites.

5.1.2 Roadway Characteristics of Reference Sites

Based on the characteristics of treatment sites, Table 19 from Chapter 4 is updated; these updates are listed in Table 25.

Table 25: Reference Sites Filters

Variable	Attribute
Route Type	1 – State Route
Dividing Highway Barrier Type	0 – No Barrier
Dividing Highway Median Type	0 – Undivided Road
Functional Classification	2 – Rural – Principal Arterial 6 – Rural – Minor Arterial 7 – Rural – Major Collector
Number of Left Lanes	1 – 1 lane on the left side of the roadway
Number of Right Lanes	1 – 1 lane on the right side of the roadway

This filtering of the overall crash database yielded a total of 81,930 crashes; 41,121 crashes in the before period and 40,089 crashes in the after period. In addition to applying these filters to the reference sites, these filters were also applied to the treatment sites for the comparison before-after analysis, yielding a total of 2,681 crashes; 1,379 crashes in the before period and 1,302 crashes in the after period.

5.2 Direct Before-After Analysis

For the direct before-after analysis, the number of crashes of two calendar years before and after installation of centerline rumble strips was examined. The periods of this study are:

- Before period: January 1, 2003 to December 31, 2004
- After period: January 1, 2006 to December 31, 2007

In addition to comparing the total number of crashes for each site, specific crash types and severities were examined for each site.

5.2.1 Total Crashes

A brief analysis of total crashes (i.e., regardless of crash severity or crash type) reveals that all but one of the installation sites experienced a reduction in crashes, as seen in Table 26. This change ranged from an increase in a number of crashes of 4.76% to a decrease of a number in crashes of 34.34%. The average reduction of crashes of all 10 sites was 8.80%. While this decrease could be attributed to centerline rumble strips, as mentioned previously the decrease could also be attributed to a statewide trend in crash reductions, selection bias, regression-to-the-mean, or other factors presently unknown. In the following sections regarding the direct before-after comparisons of the crash types the same caveats, however, may not be continually repeated.

Table 26: Site by Site Comparison, All Crash Types, All Crash Severities

Site	Miles	Before Crashes	After Crashes	Change (number)	Change (%)
0006693 SR 14	7.87	170	142	-28	-16.47%
0006693 SR 16	18.24	256	240	-16	-6.25%
0006693 SR 154	7.49	306	267	-39	-12.75%
0006945 SR 369	19.89	546	572	+26	+4.76%
0006975 SR 42 A	7.97	56	44	-12	-21.43%
0006975 SR 42 B	5.23	130	109	-21	-16.15%
0006976 SR 204	8.14	68	63	-5	-7.35%
0007077 SR 36 A	12.03	101	73	-28	-27.72%
0007077 SR 36 B	11.84	99	65	-34	-34.34%
0007077 SR 136	27.76	97	93	-4	-4.12%
Overall	**126.46**	**1829**	**1668**	**-161**	**-8.80%**

An examination of crashes with injuries reveals a reduction in crashes similar to that of the total crashes. As these counts are simply in terms of crashes and not persons, crashes that involve one injury and one non-injury, or crashes that involve one injury and one fatality, were included. All but one site experienced a reduction in crashes that have injuries; overall, crashes with injuries decreased by 12.84%. These results are tabulated in Table 27.

Table 27: Site by Site Comparison, All Crash Types, Crashes with Injuries

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	75	60	-15	-20.00%
0006693 SR 16	97	104	+7	+7.22%
0006693 SR 154	105	90	-15	-14.29%
0006945 SR 369	166	144	-22	-13.25%
0006975 SR 42a	24	20	-4	-16.67%
0006975 SR 42b	36	26	-10	-27.78%
0006976 SR 204	31	19	-12	-38.71%
0007077 SR 36a	37	36	-1	-2.70%
0007077 SR 36b	33	23	-10	-30.30%
0007079 SR136	50	48	-2	-4.00%
Overall	**654**	**570**	**-84**	**-12.84%**

The third area of interest examined was crashes with fatalities. As shown in Table 28, three sites experienced an increase in the number of crashes with fatalities. One site did not experience a change, while three sites experienced an increase. Overall, there was a reduction of 15.0% in crashes with fatalities on roadways with centerline rumble strips from the before period to the after period.

Table 28: Site by Site Comparison, All Crash Types, Crashes with Fatalities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	2	1	-1	-50.0%
0006693 SR 16	4	2	-2	-50.0%
0006693 SR 154	1	2	+1	+100.0%
0006945 SR 369	2	3	+1	+50.0%
0006975 SR 42a	2	0	-2	-100.0%
0006975 SR 42b	3	1	-2	-66.7%
0006976 SR 204	2	1	-1	-50.0%
0007077 SR 36a	2	2	0	0.0%
0007077 SR 36b	2	1	-1	-50.0%
0007079 SR136	0	4	+4	--
Overall	**20**	**17**	**-3**	**-15.0%**

5.2.2 Head-on Crashes

Head-on crashes describe crashes where two vehicles strike each other head-on and is one of the two types of crashes that centerline rumble strips seeks to mitigate, the other being opposite-direction sideswipe crashes. The official GDOT definition for head-on crashes can be found in Chapter 4.3. As Figure 29 shows, while head-on crashes account for 3.39% of all crashes on the treatment roadways, this crash type accounts for 6.88% of all crashes involving injuries and 50.00% of all crashes involving fatalities. In the after period, head-on crashes constitute 23.53% of all crashes involving fatalities, emphasizing the severe nature of this crash type.

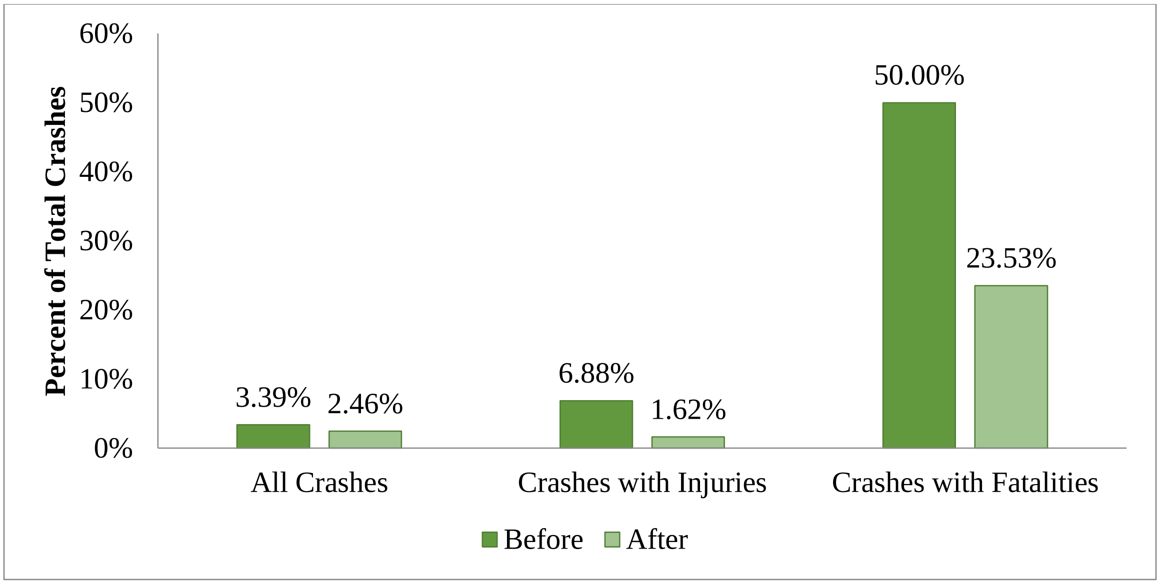


Figure 29: Proportion of All Crashes That Are Head-On Crashes

Table 29 shows that five of the sites experienced a reduction in crashes. Of the remaining five sites, two experienced an increase in crashes, while three did not experience a change in the number of head-on crashes. Of all 10 sites, the number of head-on crashes decreased by 33.9%.

Table 29: Site by Site Comparison, Head-on Crash Type, All Crash Severities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	18	8	-10	-55.6%
0006693 SR 16	12	8	-4	-33.3%
0006693 SR 154	8	4	-4	-50.0%
0006945 SR 369	11	11	0	0.0%
0006975 SR 42a	1	2	+1	+100.0%
0006975 SR 42b	1	1	0	0.0%
0006976 SR 204	0	0	0	--
0007077 SR 36a	5	1	-4	-80.0%
0007077 SR 36b	3	2	-1	-33.3%
0007079 SR136	3	4	+1	+33.3%
Overall	**62**	**41**	**-21**	**-33.9%**

A closer examination of just crashes with injuries reveals a similar reduction in the number of crashes, as tabulated in Table 30. Five sites experienced a reduction in crashes. Of the five sites that did not experience a crash reduction, three remained the same at zero crashes per study period, while two increased by two crashes. The overall crash reduction for head-on crashes with injuries was 40.0%.

Table 30: Site by Site Comparison, Head-on Crash Type, Crashes with Injuries

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	14	2	-12	-85.7%
0006693 SR 16	10	8	-2	-20.0%
0006693 SR 154	4	1	-3	-75.0%
0006945 SR 369	9	6	-3	-33.3%
0006975 SR 42a	0	2	+2	--
0006975 SR 42b	1	1	0	0.0%
0006976 SR 204	0	0	0	--
0007077 SR 36a	3	1	-2	-66.7%
0007077 SR 36b	2	2	0	0.0%
0007079 SR136	2	4	+2	+100.0%
Overall	**45**	**27**	**-18**	**-40.0%**

The final comparison was of head-on crashes that involved fatalities. Six sites experienced a decrease in fatalities, as tabulated in Table 31. Of the four remaining sites, two remained at zero fatalities, while two increased by one fatality. The overall crash reduction in head-on crashes with fatalities was 60.0%. It is important to note that this is based on a small sample size of 10 therefore the comparison of fatalities is subject to considerable randomness.

Table 31: Site by Site Comparison, Head-on Crash Type, Crashes with Fatalities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	1	0	-1	-100.0%
0006693 SR 16	2	1	-1	-50.0%
0006693 SR 154	1	0	-1	-100.0%
0006945 SR 369	2	1	-1	-50.0%
0006975 SR 42a	0	0	0	--
0006975 SR 42b	0	1	+1	--
0006976 SR 204	0	0	0	--
0007077 SR 36a	2	0	-2	-100.0%
0007077 SR 36b	2	0	-2	-100.0%
0007079 SR136	0	1	+1	--
Overall	**10**	**4**	**-6**	**-60.0%**

5.2.3 Opposite-Direction Sideswipe Crashes

Opposite-direction sideswipe crashes are the other type of crash that centerline rumble strips seek to mitigate. While the initial impact of the two vehicles may not be as severe as those of a head-on collision, opposite-direction sideswipe crashes still involve a vehicle’s encroachment onto the centerline, where the vehicle could then sideswipe an opposing vehicle and possibly overcorrect or spin out of control. The official GDOT definition of opposite-direction sideswipe crashes can be found in Chapter 4.3. Filtering the crashes to only those with opposite-direction sideswipe crashes reveal a greater reduction in crashes than the overall crash rate reduction. Figure 30 shows the proportion of crashes categorized as opposite-direction sideswipe.

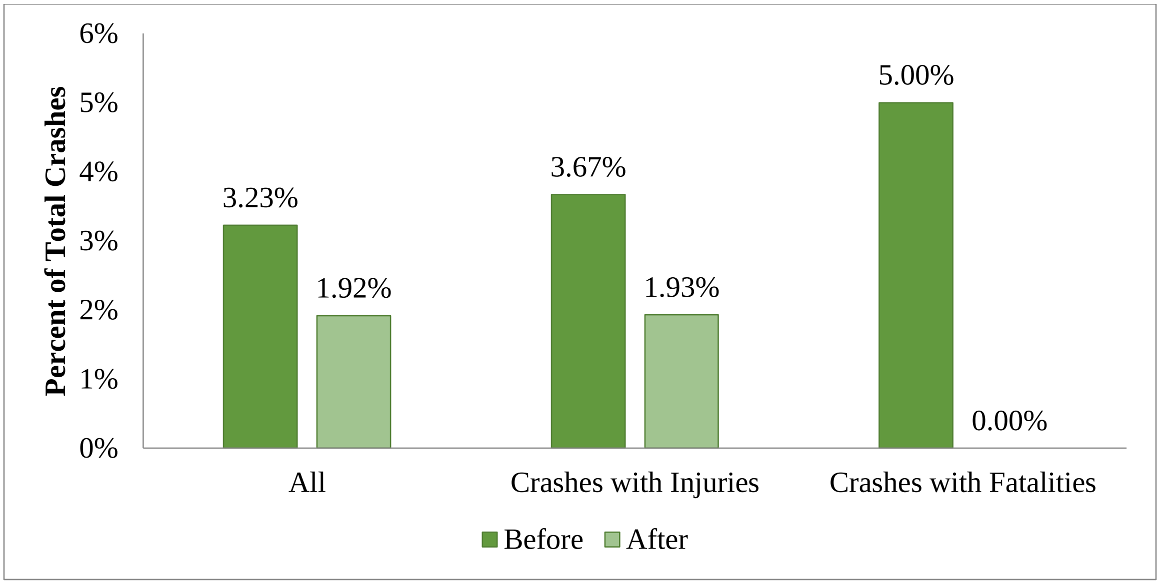


Figure 30: Proportion of All Crashes That Are Opposite-Direction Crashes

This crash type represents 3.32% of the total crashes on the study roadways, 3.67% of these crashes involve injuries, and 5.00% of these crashes involve fatalities. Table 32 shows the site by site comparison of this crash type.

Table 32: Site by Site Comparison, Opposite-Direction Crash Type, All Crash Severities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	9	5	-4	-44.4%
0006693 SR 16	9	4	-5	-55.6%
0006693 SR 154	6	3	-3	-50.0%
0006945 SR 369	22	12	-10	-45.5%
0006975 SR 42a	2	2	0	0.0%
0006975 SR 42b	2	1	-1	-50.0%
0006976 SR 204	1	1	0	0.0%
0007077 SR 36a	1	1	0	0.0%
0007077 SR 36b	5	1	-4	-80.0%
0007079 SR136	2	2	0	0.0%
Overall	**59**	**32**	**-27**	**-45.8%**

An examination of opposite-direction sideswipe crashes that resulted in injuries reveals that all but one of the 10 sites experienced a reduction in crashes, as tabulated in Table 33.

Table 33: Site by Site Comparison, Opposite-Direction Crash Type, Crashes with Injuries

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	3	1	-2	-66.7%
0006693 SR 16	4	3	-1	-25.0%
0006693 SR 154	2	1	-1	-50.0%
0006945 SR 369	8	4	-4	-50.0%
0006975 SR 42a	2	0	-2	-100.0%
0006975 SR 42b	0	1	+1	--
0006976 SR 204	1	0	-1	-100.0%
0007077 SR 36a	1	0	-1	-100.0%
0007077 SR 36b	1	0	-1	-100.0%
0007079 SR136	2	1	-1	-50.0%
Overall	**24**	**11**	**-13**	**-54.2%**

The final comparison of opposite-direction sideswipe crashes reveal that this crash type does not produce many fatalities, as shown in Table 34. Of all 10 sites, only one experienced a fatality in the before period. None of the 10 sites experienced a fatality in the after period.

Table 34: Site by Site Comparison, Opposite-Direction Sideswipe Crash Type, Crashes with Fatalities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	0	0	0	--
0006693 SR 16	0	0	0	--
0006693 SR 154	0	0	0	--
0006945 SR 369	0	0	0	--
0006975 SR 42a	1	0	-1	-100.0%
0006975 SR 42b	0	0	0	--
0006976 SR 204	0	0	0	--
0007077 SR 36a	0	0	0	--
0007077 SR 36b	0	0	0	--
0007079 SR136	0	0	0	--
Overall	1	0	-1	-100.0%

5.2.4 Not a Collision with a Motor Vehicle

The third crash type examined is "not a collision with a motor vehicle." These crashes include crashes that ran off the road to the left, ran off the road to the right, crashes with animals, or crashes with debris on the road. However, this crash type excludes crashes with pedestrians. Though this crash type includes a wide variety of crashes, it is important to consider this crash type as it includes crashes that encroach or cross over the centerline. The official GDOT definition of this crash type can be found in Chapter 4.3. In the crash database, all crashes that involve one vehicle are classified as "not a collision with a motor vehicle." Figure 31 shows the proportion of this crash type to all crashes on the study roadways.

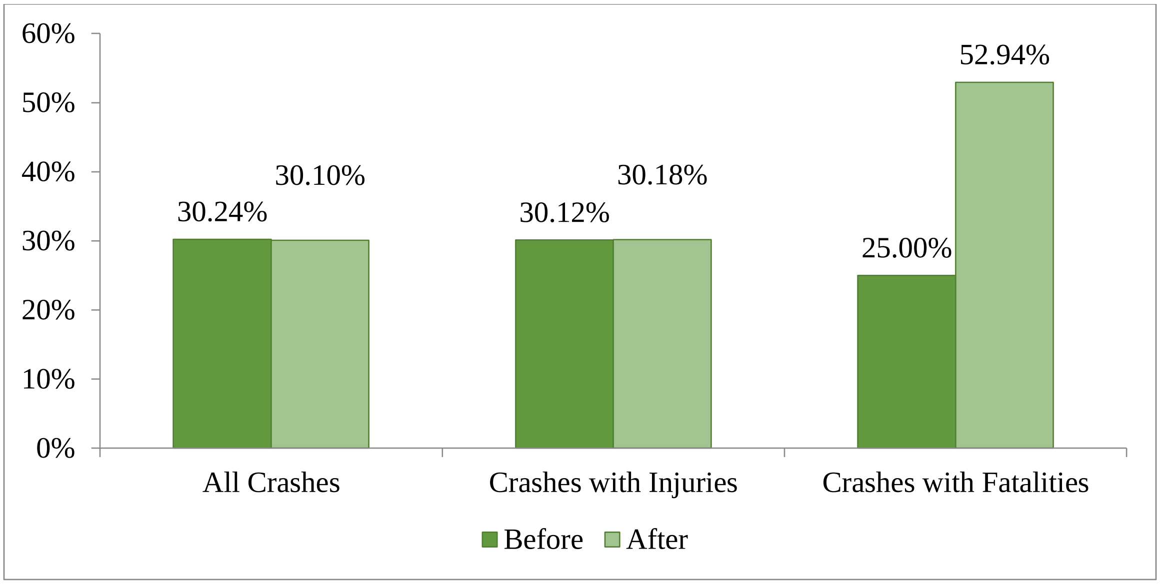


Figure 31: Proportion of All Crashes That Are Not a Collision with a Motor Vehicle

As seen in this figure, the proportion of crashes that are classified as "not a collision with a motor vehicle" does not change much for all crashes and crashes that involve injuries. However, crashes that involve fatalities increased from 25.0% of all crashes that involved fatalities to 52.9%. Table 35 shows the site by site comparison of this crash type.

Table 35: Site by Site Comparison, Not a Collision with a Motor Vehicle Crash Type, All Crash Severities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	37	34	-3	-8.1%
0006693 SR 16	76	69	-7	-9.2%
0006693 SR 154	34	36	+2	+5.9%
0006945 SR 369	130	131	+1	+0.8%
0006975 SR 42a	22	16	-6	-27.3%
0006975 SR 42b	44	27	-17	-38.6%
0006976 SR 204	36	38	+2	+5.6%
0007077 SR 36a	54	42	-12	-22.2%
0007077 SR 36b	58	43	-15	-25.9%
0007079 SR136	62	66	4	+6.5%
Overall	**553**	**502**	**-51**	**-9.2%**

Overall, the number of crashes classified as “not a collision with a motor vehicle” decreased by 9.2%. An examination of crashes of this type that resulted in injuries reveals that all but one of the 10 sites experienced a reduction in crashes with injuries, as tabulated in Table 36. However, the one site that experienced an increase in crashes increased by nearly 150%.

Table 36: Site by Site Comparison, Not a Collision with a Motor Vehicle Crash Type, Crashes with Injuries

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	14	14	0	0.0%
0006693 SR 16	23	21	-2	-8.7%
0006693 SR 154	7	17	+10	+142.9%
0006945 SR 369	48	40	-8	-16.7%
0006975 SR 42a	12	8	-4	-33.3%
0006975 SR 42b	10	5	-5	-50.0%
0006976 SR 204	17	10	-7	-41.2%
0007077 SR 36a	17	16	-1	-5.9%
0007077 SR 36b	15	12	-3	-20.0%
0007079 SR136	34	29	-5	-14.7%
Overall	**197**	**172**	**-25**	**-12.7%**

The final comparison of crashes classified as “not a collision with a motor vehicle” reveals that this crash type does not have a large fatality sample size, as shown in Table 37. However, four sites experienced an increase in fatalities.

Table 37: Site by Site Comparison, Not a Collision with a Motor Vehicle Crash Type, Crashes with Fatalities

Site	Crashes (before)	Crashes (after)	Change (number)	Change (%)
0006693 SR 14	1	1	0	0.0%
0006693 SR 16	1	1	0	0.0%
0006693 SR 154	1	1	0	0.0%
0006945 SR 369	0	1	+1	--
0006975 SR 42a	0	0	0	--
0006975 SR 42b	0	0	0	--
0006976 SR 204	2	0	-2	-100.0%
0007077 SR 36a	0	1	+1	--
0007077 SR 36b	0	1	+1	--
0007079 SR136	0	3	+3	--
Overall	**5**	**9**	**+4**	**+80.0%**

5.3 Comparison Before-After Analysis

Taking the direct before-analysis one step further, the before-after comparison analysis incorporates the crash reductions of sites with characteristics similar to the study sites. In this analysis, the treatment sites were analyzed as a whole rather than site by site; similarly, the reference sites were analyzed as a whole. The study periods examined are the same as the Direct Before-After analysis:

- Before period: January 1, 2003 – December 31, 2004
- After period: January 1, 2007 – December 31, 2008

Rather than comparing direct numbers, the percent reduction between the before and after periods of various crash types and severities are examined and compared. If the percent reduction in crashes of the treatment sites is greater than the percent reduction in crashes of the reference sites, it provides further indication that the centerline rumble strips could be an effective safety countermeasure. As stated previously, while regression-to-the-mean and selection bias remain an issue with this approach, and thus results must be viewed cautiously, general trends in crash rates, weather influences, incident reporting changes, etc. are at least partially reflected. The number of crashes in this portion of the study is listed in Table 38. Immediately, it can be seen that the crash reduction of the treatment sites is greater than the crash reduction of the reference sites.

Table 38: Number of Crashes of the Two Groups

Time Period	Treatment Sites Crashes	Reference Sites Crashes
Before	1,379	41,121
After	1,302	40,809
Overall	**-5.58%**	**-0.76%**

The treatment sites and reference sites characteristics are listed in Table 39.

Table 39: Reference Sites Characteristics

Variable	Description
Route Type	1 – State Route
Highway Barrier Type	0 – No Barrier
Highway Median Type	0 – Undivided Road
Functional Classification	2 – Rural – Principal Arterial 6 – Rural – Minor Arterial 7 – Rural – Major Collector
Number of Left Lanes	1 – 1 lane on the left side of the roadway
Number of Right Lanes	1 – 1 lane on the right side of the roadway
Excluding	Roadway segments in CLRS roadway database

5.3.1 All Crash Types

In comparing the overall crash reduction, Table 40 and Figure 32 reveal that the treatment sites experienced a 5.58% decrease in crashes involving both fatalities and injuries, while the reference sites experienced a 0.76% decrease. This pattern is repeated through all other analyzed crash severities, culminating in a 14.48% decrease in crashes involving injuries in the treatments sites, while the reference sites experienced a 4.75% decrease in crashes in the same category.

Table 40: Before-After Crashes by Injury Severity, Overall Crashes

	Treatment			Reference		
	Before	After	Change	Before	After	Change
Overall	1,379	1,302	-5.58%	41,121	40,809	-0.76%
Fatalities	15	14	-6.67%	614	586	-4.56%
Injuries	504	431	-14.48%	15,294	14,568	-4.75%

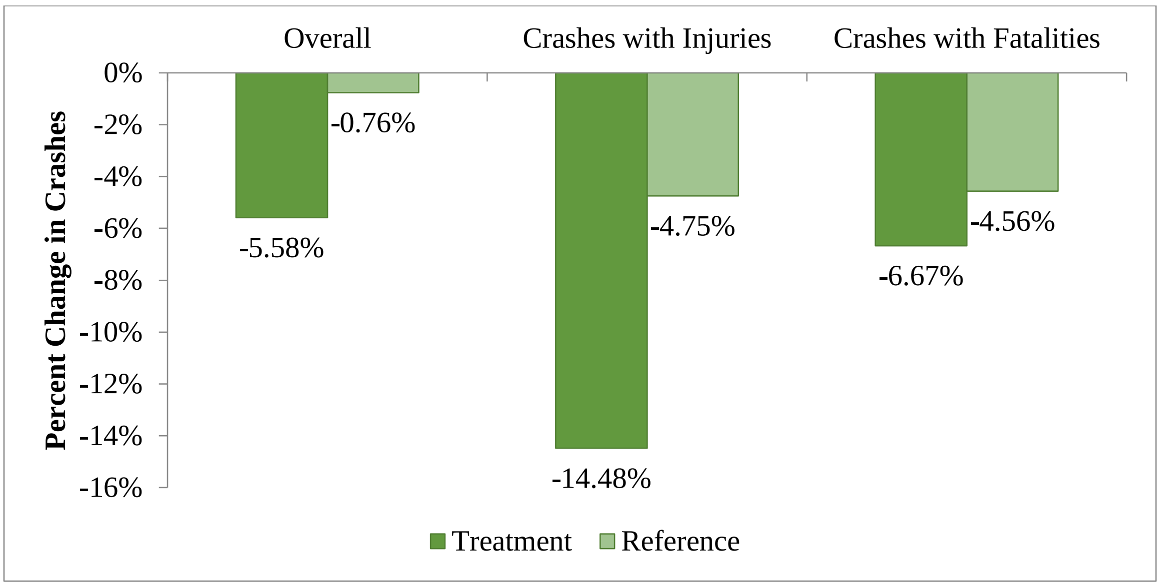


Figure 32: Before-After Change by Injury Severity, Overall Crashes

Though this suggests that centerline rumble strips are effective in reducing overall crashes, crashes with fatalities, and crashes with injuries, it is important recall that other factors not presently known may also contribute to the greater crash reduction of the treatment sites. For instance, the treatment sites may have been selected because of higher crash rates (selection bias) increasing the likelihood of a decrease in crashes even without the treatment (regression-to-the-mean).

5.3.2 Specific Crash Types

In addressing various crash types, the treatment sites experienced a greater reduction in both head-on crashes and opposite-direction sideswipe crashes than the reference sites, as tabulated in Table 41 and shown in Figure 33. The crash types that experienced the largest reductions in the treatment sites were head-on crashes and opposite-direction sideswipe crashes. Both of the crash reductions of these types were greater in the treatment sites than the reference sites.

Table 41: Before-After Change by Crash Type, Overall Crashes

	Treatment			Reference		
	Before	**After**	**Change**	**Before**	**After**	**Change**
Head-on	49	36	-26.53%	1,091	1,034	-5.22%
Opposite-Direction Sideswipe	52	27	-48.08%	1,101	1,038	-5.72%
Angle	239	232	-2.93%	8,620	8,178	-5.13%
Not a Collision with a Motor Vehicle	465	427	-8.17%	18,156	18,740	+3.22%

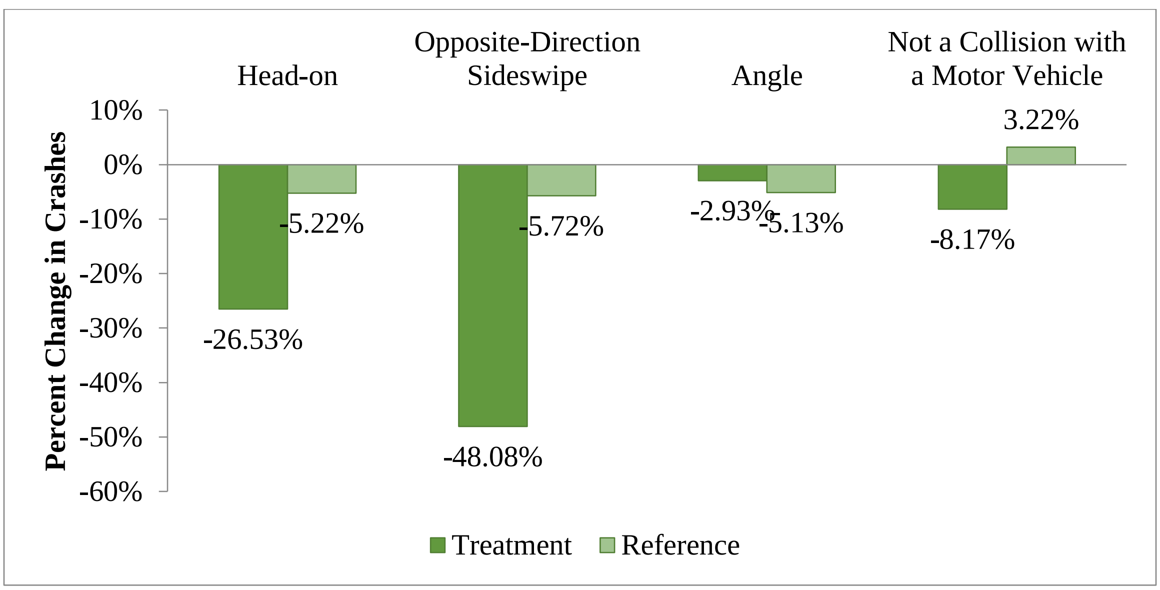


Figure 33: Before-After Change by Crash Type, Overall Crashes

While the reference sites experienced a greater decrease in angle crashes, it is clear that the treatment sites experienced a greater reduction in the crash types that centerline rumble strips target providing a potential indication that the CLRS contributed to a safety improvement.

5.4 Comparative Analysis

In this study, the comparative analysis examined the crash rates of 2003 through 2008 where crashes that occurred on the treatment roadways with centerline rumble strips were compared to the crashes that occurred on a set of reference roadways without centerline rumble strips in order to determine how centerline rumble strips affect crash frequencies in Georgia. The reference roadways were chosen based on characteristics similar to the treatment roadways, namely the number of lanes, the route type, and the lack of a dividing median or barrier. The effectiveness of centerline rumble strips was determined based on the resulting crash modification factor (CMF) of each bin. If the CMF was below 1.0, it may be said that centerline rumble strips lead to fewer crashes on roadway segments and the particular AADT on which centerline rumble strips were installed. Crashes and vehicle-miles-traveled (VMT) were determined for each AADT bin for both the treatment roadways and the reference roadways. Ultimately, this produced mixed results, with CMFs ranging from well below 1.0 to well above 1.0 depending on the AADT.

5.4.1 Fixed AADT Bins

For the comparative analysis, reference and treatment sites were matched with AADT bin sizes of 500, 1000 and 2,000 vpd. The smaller bins sizes produced wide variability in the calculated CMFs due both to the reduction in sample size because of a smaller bin width and, in the case of the smaller VMT values, wide variability due to low absolute crash numbers. The results for the analyses of the 500 and 1,000 vpd binning are presented in Appendix D and the results for the 2,000 vpd binning are presented here.

The VMT distribution for the treated roadways for the bins of 2,000 vpd is shown Figure 34.

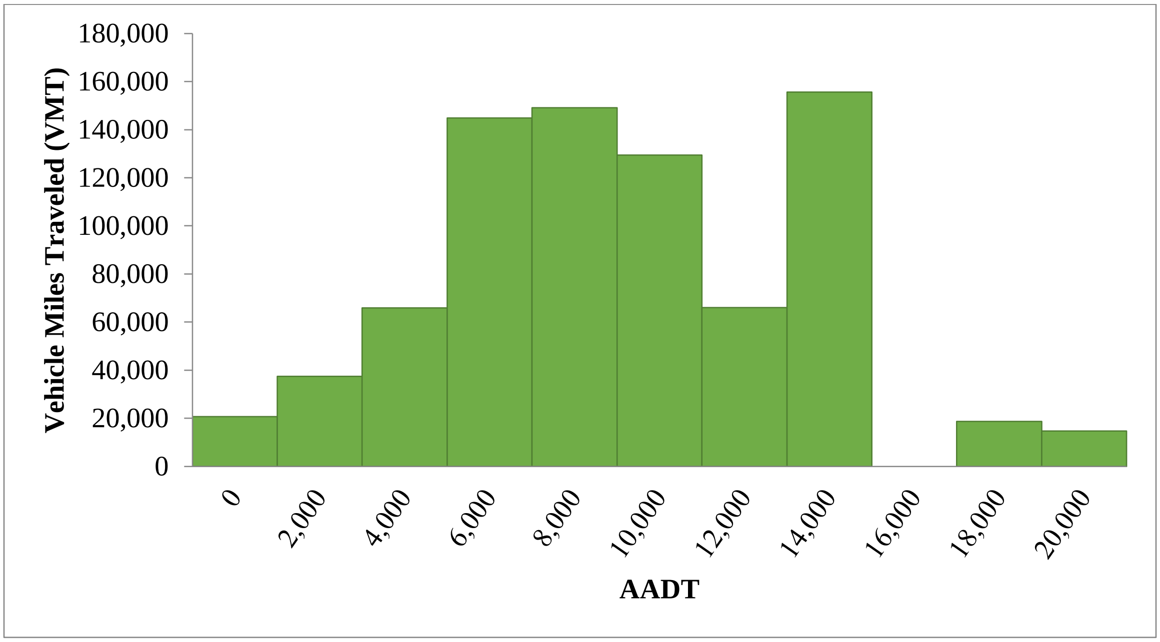


Figure 34: VMT Distribution of Treatment Roadways with AADT Bins of 2,000

Because the AADT bins of 2,000 vpd incorporated a wider range of traffic volumes, each bin consists of a number of roadway segments and thus more VMTs. Figure 35 and Figure 36 show the calculated CMFs for the AADT bins of 2,000 vpd.

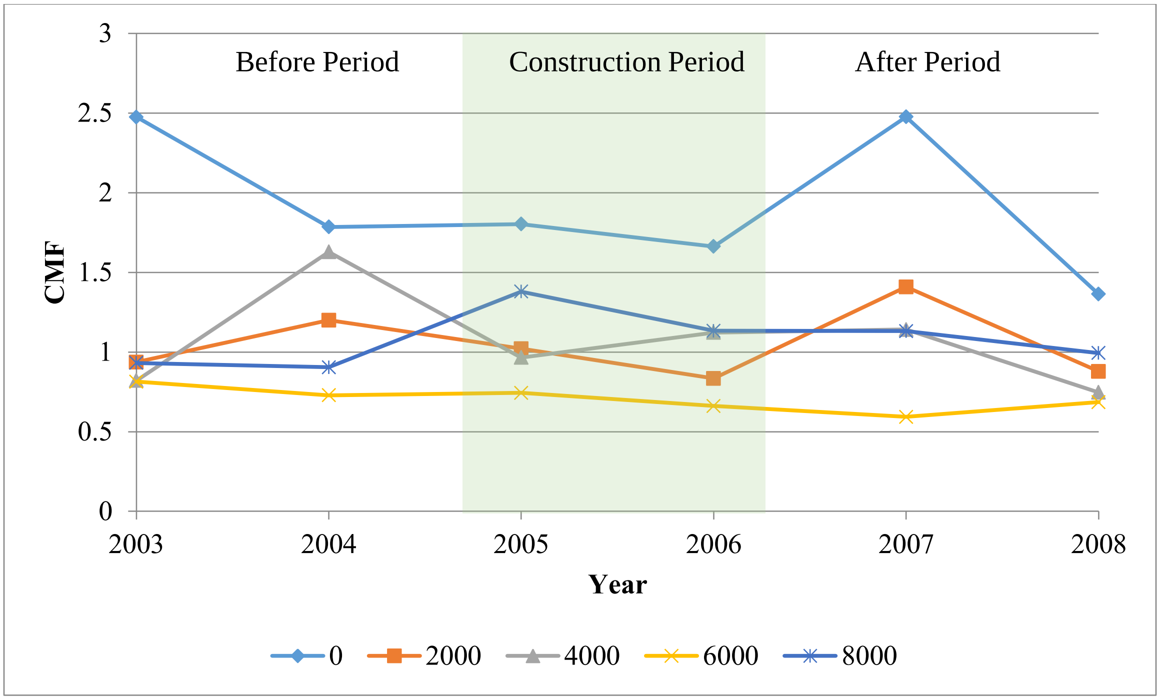


Figure 35: Bins of 2,000 – CMFs of Roadway Segments with AADTs of 0 to 9999 vpd

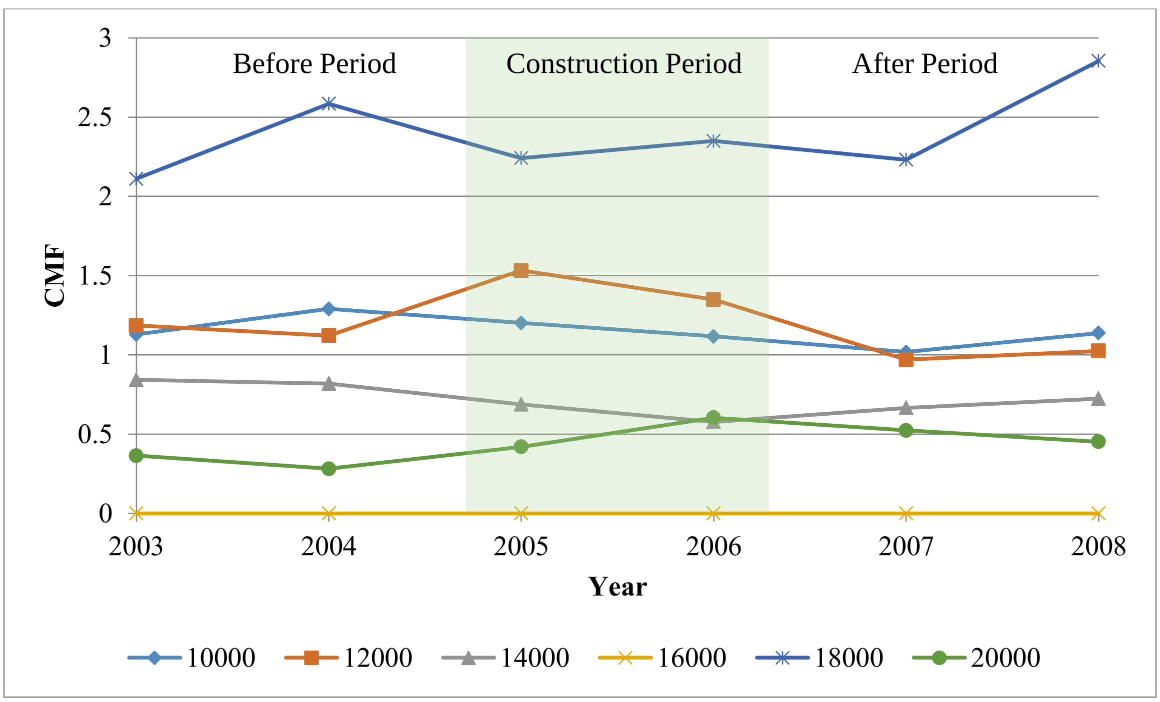


Figure 36: Bins of 2,000 – CMFs of Roadway Segments with AADTs of 10000 to 20000+ vpd

With this larger binning, the CMFs were less susceptible to change due to differences of a few crashes. It can be seen that crashes on roadway segments in about half of the AADT bins of 2,000 vpd decreased from 2003 to 2008. Though nominally noticeable, this trend can be seen in AADT bins of 0 to 1,999 vpd, 6,000 to 7,999 vpd, 10,000 to 11,999 vpd, 12,000 to 13,999 vpd, and 14,000 to 15,999 vpd.

An important consideration for these results is that for the before data there is no treatment. Thus, if all other factors were equal one should expect the CMF to be 1.0, as there is no difference between the treatment roadways and the reference roadways. However, it is clear that this is not the case. It is possible that the CMF differences from 1.0 in the before period are a result of the random nature of incident data. However, selection bias, regression-to-the-mean, or other unknown factors may also be contributors to this difference. It is of potential interest that the before and after CMF values for each particular range are relatively consistent (i.e., above or below 1.0 in both before and after periods). This undermines some of the before-after results, potentially indicating that the impacts seen are not attributable to centerline rumble strips.

5.4.2 AADT Bins of Logarithmic Distribution

The last set of AADT bins examined represents an approximate logarithm distribution, in which the AADT bins sizes increase with as AADT values. In addition, roadways with AADTs of less than 2,000 vpd were excluded as results from Chapters 5.4.1 through 5.4.3 reveal that there was insufficient data in these ranges to extract meaningful results. Figure 37 shows the VMT distribution for the treated roadways for each AADT bin.

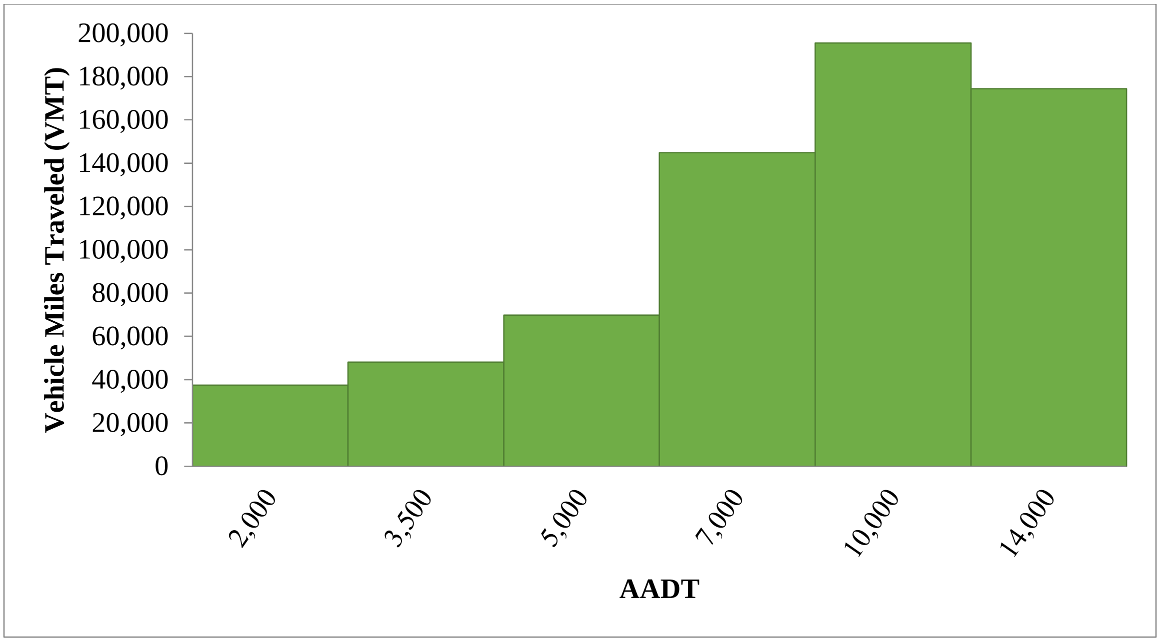


Figure 37: VMT Distribution of Treatment Roadways with AADT Bins of Logarithmic Distribution

Unlike other VMT distributions, this distribution does not have AADT bins where there were no roadway segments. In addition, the least traveled road was greater than 35,000 vehicle-miles traveled. This led to the discovery of a CMF trend from 2003 to 2008, as shown in Figure 38.

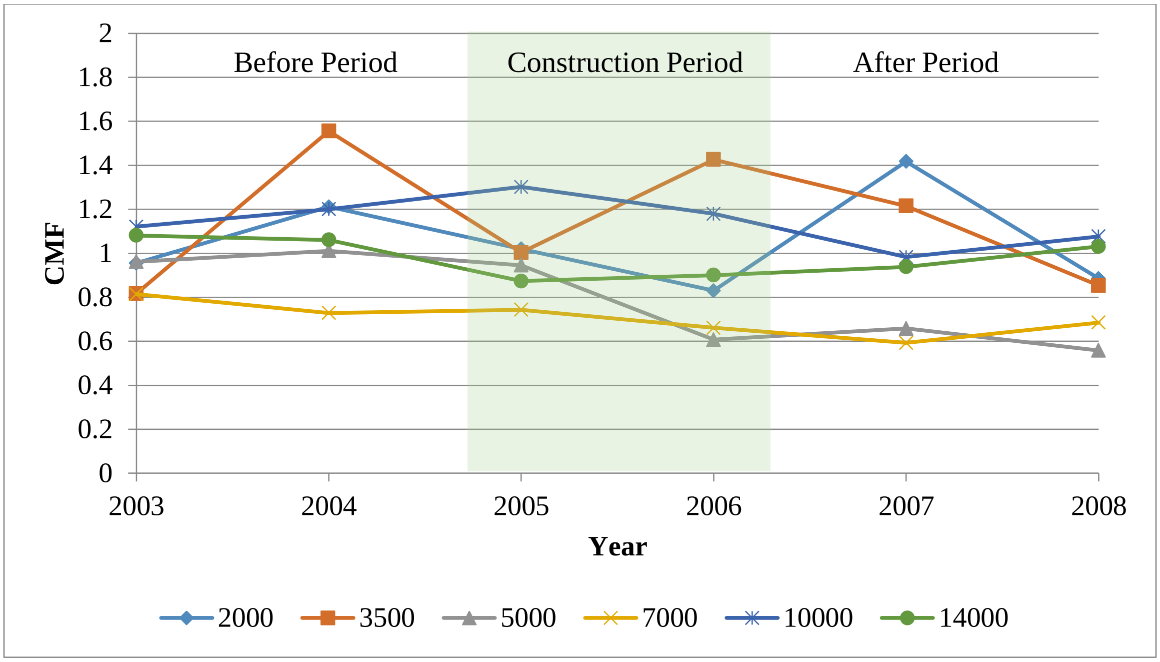


Figure 38: Bins of Logarithmic Distribution – CMFs of Roadway Segments with AADTs of 2000 to 14000+ vpd

In this figure, it can be seen that every AADT bin experienced a slight net reduction in CMFs between 2003 and 2008. Although the reduction seems nominal from this figure, normalizing the CMFs by the respective VMTs reveals a greater impact. As seen in Figure 39, the CMF averages at 1.03 in the two years prior to construction, dropping throughout the construction periods of 2005 and 2006 down to an average of 0.90 in the two years after construction. This is similar to the suggested CMF for centerline rumble strips presented in the Highway Safety Manual [20].

Figure 39: Normalized CMFs by VMT from 2003 to 2008

However, caution must be exercised with this result as it is still subject to regression-to-the-mean and selection bias. In particular, the before CMF values of greater than 1.0, where no actual treatment exists, is a potential indication of selection bias where centerline rumble strips were implemented on higher incident roadways. This could then imply that a portion of the after benefit is a result of regression-to-the-mean. One clear indication of this result is that the next step in this research should be an implementation of a full empirical bays analysis.

CHAPTER 6

CONCLUSIONS, LIMITATIONS, AND FURTHER RESEARCH

The purpose of this study was to analyze the safety effectiveness of centerline rumble strips in the state of Georgia. Though other state DOTs have conducted and concluded that centerline rumble strips have a positive effect on roadways, driving behavior, the topography on which the roads are built on, and construction methods differ from region to region around the United States. This variation necessitated an analysis of centerline rumble strips in the context of Georgia.

Initially, a survey was conducted to determine both the current state of practice of centerline rumble strips and any potential safety and maintenance impacts from centerline rumble strips. Next, prior to the analyses, roadway characteristics and crash rates were verified for each of the centerline rumble strips installation sites (treatment sites) and control sites (reference sites). Lastly, several in-depth analyses were conducted using the crash data and roadway data. The following sections briefly discuss the results presented in this thesis.

6.1 Survey Results

A survey was conducted in order to ascertain the status of centerline rumble strips implementation and potential issues from around the United States. At the time of this study, results from the survey represent 28 states DOTs; a response rate of 56%. From the survey, respondents indicated that their state DOTs are generally in favor of centerline rumble strips and are continuing to invest in implementation of centerline rumble strips. In addition, only a handful of respondents indicated maintenance related issues. As discussed in the literature review, respondents attribute much of the increased maintenance to poor initial roadway conditions prior to centerline rumble strips installation. From the survey, it is clear that state DOTs believe that centerline rumble strips are a relatively inexpensive method to effectively reduce cross-over crashes.

6.2 Treatment Sites

The treatment sites represented in this study consisted of roadways with centerline rumble strips installations. These roadways totaled 126.46-miles which were divided into 10 different installation sites, representing different regions, climates, topographies, and driving behaviors. As centerline rumble strips were implemented throughout 2005 and 2006, the study periods were determined to be two calendar years before and after this implementation. The periods in this study were:

- Before period: January 1, 2003 to December 31, 2004
- After period: January 1, 2007 to December 31, 2008

The crash frequencies were compared between these two time periods.

6.3 Preliminary Before-After Analyses

Both the direct before-after analysis and the comparison before-after analysis indicated that the roadways on which centerline rumble strips were installed experienced a reduction in crash frequencies. An examination of all 10 sites revealed that the crash frequency was reduced by 8.80% for all crashes, 12.84% for crashes that involved injuries, and 15.0% for crashes that involved fatalities. In addition to the overall results, the crash reductions of various crash severities and severities were noteworthy. For crashes that were classified as head-on crashes, the crash frequency was reduced by 33.9%; 40.0% for crashes that involved injuries, and 60.0% for crashes that involved fatalities. For crashes that were classified as opposite-direction sideswipe crashes, the crash frequency was reduced by 45.8%; 54.2% for crashes that involved injuries, and 100% for crashes that involved fatalities. However, as with all naïve before-after studies these results must be tempered. It is possible that the findings are the result of selection bias, regression-to-the-mean, changes in driver behaviors, changes in crash reporting, or other unknown factors.

The comparison before-after analysis revealed that for all crash severities, roadways with centerline rumble strips experienced a larger crash reduction than roadways without centerline rumble strips. Overall, crashes on roadways with centerline rumble strips decreased by 5.58% overall compared to a reduction of 0.76% on the reference roadways, a 14.48% reduction on the treatment roadways for crashes that involved injuries compared to a 4.75% reduction on the reference roadways, and a 6.67% reduction in crashes with fatalities compared to a reduction of 4.56% on the reference roadways. In terms of crash types, head-on crashes experienced a reduction of 26.53% on treatment roadways compared to a reduction of 5.22% on reference roadways, and opposite-direction sideswipe crashes experienced a reduction of 48.08% on treatment roadways compared to a reduction of 5.72% on reference roadways. Once again, it should be noted that while results from a comparison analysis may help control for general trends, selection bias, regression to the mean, and other unknown variables may adversely impact the results. In addition one challenge in the application of these results is the sample size; the crash frequencies for specific crash types were very low to begin with. Therefore, any percent change may be exaggerated.

6.4 Comparative Analysis

The comparative analysis was conducted to obtain a better estimation of the safety effectiveness of centerline rumble strips on roadways in the state of Georgia. Instead of directly comparing the frequency of crashes of the before period to the after period, the comparative analysis pulled in information regarding the roadways on which the centerline rumble strips were installed, the treatment roadways, and similar roadways throughout Georgia, the reference roadways. This information included the AADTs and

VMTs of these roadways, which allowed the calculation of crash modification factors, or CMFs.

The CMFs were calculated for a variety of AADT bins. It was found that the bins modeled after a logarithmic distribution showed not only a secular trend of decreasing CMFs from the before period to the after period, but also a normalized expected crash reduction. However, caution must be exercised with this result as it is still subject to regression-to-the-mean and selection bias. In particular, the before period CMF values of greater than 1.0, where no actual treatment exists, is a potential indication of selection bias where centerline rumble strips may have been implemented on roadways with higher incident rates. This could then imply that a portion benefit seen in the after period is a result of regression-to-the-mean. One clear indication of this result is that the next step in this research should be an implementation of a full empirical bays analysis.

6.5 Limitations

There were a number of limitations to this study. One limitation was the lack of extensive crash data. Initially, this study was designed to examine three calendar years before and after centerline rumble strips implementation. However, the crash data for 2009 was largely incomplete, and thus the study was limited to two calendar years before and two calendar years after implementation. In addition, the incomplete nature of the 2009 data revealed reasons for concern about the completeness of the crash data for the years analyzed in this study; for this study, it was assumed that any incompleteness in the crash data for 2003 through 2008 would be systemic in nature.

A second limitation is the potential for human error in the creation of the crash and roadway databases used for this study. Most of the information in the crash databases were initially recorded by the police officer at the scene of the crash and is subject to human error. This information includes the crash severity and the manner of collision (i.e., the crash type). In addition, the methodology on how information in the roadway databases were classified, such as roadway functional classification (e.g., rural or urban) was not available.

Similar to the second limitation, the method of assigning mileposts to the roadways was found to differ from database to database. In this study, it was generally assumed that the mileposts listed for each crash in the crash database was correct. However, this may not be the case. Future studies should examine the individual police reports of all crashes on the treatment roadways and determine exactly where the crash occurred.

Third, the method of obtaining AADT counts for roadway segments is a limitation in this study. The majority of the AADT counts were not done manually or at the site, but rather were estimates based on an algorithm. As much of the comparative analysis relies heavily on AADT, there may be room for error within the results due to this method of determining AADT for the roadway segments.

A fourth limitation is the potential for errors in how the research team obtained the appropriate crash records from the crash and roadway databases. For example, as the beginning and ending mileposts of the centerline rumble strips installation sites were initially incorrect, the methodology of determining the appropriate study locations was based on explorations performed by the research team using a variety of resources such as Google Maps, Google Earth, or Google Street View. Overall, though any error was assumed to be systemic in nature across all crashes and roadways, human error will always be an inherent part of data collection and research techniques.

Finally, the most significant limitation is that the current results are subject to selection bias, regression-to-the-mean, and the potential impact of other factors beyond the treatment of centerline rumble strips implementation. Thus, it is not possible to make any statements with confidence regarding the impact of centerline rumble strips until these issues are better resolved.

6.6 Further Research

The primary goal of this research was to determine the safety impacts of centerline rumble strips on roadways in Georgia. Though this study indicates that centerline rumble strips have a potential positive impact on safety in Georgia, the conclusions were solely based on the number of crashes and basic roadways characteristics throughout the state. Therefore, in order to determine exactly what extent centerline rumble strips impact safety in Georgia, other factors and variables that affect crash frequencies must be investigated.

First and foremost the analysis needs to be expanded to a complete empirical Bayes analysis in order to account for selection bias and regression-to-the-mean issues. In addition, this would facilitate in determining impacts solely from centerline rumble strips by accounting for impacts from changes in traffic volumes, roadway geometry changes, etc.

Next, for the analyses in this study, nearly the entire length of roadways with centerline rumble strips was examined as it was not possible to confidently separate intersection related crashes from non-intersection related crashes. However, centerline rumble strips are not typically installed in areas with an auxiliary left turn lane or at intersections and their approaches. Therefore, future studies may want to investigate only crashes where an intersection was not a factor. This could be accomplished by examining individual police reports and utilizing GIS tools to isolate crashes that occurred on roadway segments.

Third, it was assumed that any safety impacts from factors other than VMT were consistent in both roadways with centerline rumble strips and similar roadways that did not have centerline rumble strips. However, in order to obtain a true estimate on how effective centerline rumble strips are, the impact of factors such as but not limited to lane width, period of day, or presence of horizontal curves need to be quantified. Once these impacts are quantified, the changes in crash frequencies solely attributed to centerline rumble strips can be attained.

Fourth, a benefit-cost analysis could be conducted on centerline rumble strips in Georgia. Though centerline rumble strips are a relatively inexpensive countermeasure to various crash types, limited state resources are still required in its construction. Thus, the findings of a benefit-cost analysis could further encourage or discourage additional centerline rumble strips installations throughout the state.

Lastly, though these results are representative of Georgia, they are not necessarily representative of the southeastern region of the United States. Thus, future research could be conducted with the assistance of neighboring state DOTs to determine the safety impacts of centerline rumble strips that is representative of the entire region. The findings of these studies would also encourage or discourage the spending of state funds on centerline rumble strips throughout the Southeast.

Ultimately, as this thesis serves as a preliminary investigation as to how centerline rumble strips impact roadway safety on rural, two-way, two-lane roads in Georgia there is much potential for future research in order to attain a more complete understanding at how centerline rumble strips impact the safety of the roadways on which millions of motorists use every day.

APPENDIX A

SURVEY RESULTS

In order to address Georgia's maintenance issues and determine whether there are other issues associated with centerline rumble strips, a survey detailing requesting for this information was sent to all 50 state transportation DOTs in September, 2013. This survey was developed using SurveyMonkey and was sent to various contacts via e-mail. The contacts were discovered using state DOT websites' contact forms or directories. If the contact did not respond within the month, a reminder e-mail was sent. This appendix lists the questions to the survey followed by the answers received from various state DOTs. As of November, 2013, contacts from 28 state DOTs have responded to the survey. These states are:

Alabama	Iowa	New Hampshire
Arizona	Kansas	Oklahoma
Arkansas	Kentucky	Pennsylvania
California	Louisiana	Rhode Island
Colorado	Maine	Tennessee
Connecticut	Michigan	Vermont
Delaware	Mississippi	Washington
Florida	Nebraska	West Virginia
Illinois	Nevada	
Indiana	New Jersey	

Survey

Contact Information

The Georgia Institute of Technology in Atlanta, GA, working in association with the Georgia Department of Transportation (GDOT), is investigating pavement failure along the centerline joint at several centerline rumble strip sites in the state of Georgia. As part of this investigation we are seeking to determine whether other transportation agencies have also experienced issues with roadways on which centerline rumble strips have been installed and any mitigation measures that may have been implemented.

To help obtain this information, we hope you will be willing to complete the attached survey, or if you are not the correct person to complete this survey, to direct us to the correct contact. The survey should take no more than 15 minutes.

The results of this survey will be used by Georgia Tech researchers and GDOT. You will have the opportunity to receive a final copy of this report.

Your participation and expertise are invaluable and we sincerely thank you for your time and responses. If you have any questions, please do not hesitate to email michael.hunter@ce.gatech.edu or jerome.sin@gatech.edu.

Note: Questions with an asterisk (*) require answers.

1. Contact Information:
    - Name:
    - Title:
    - Email:
    - Phone:
    - Agency/Organization:
2. What is your area of expertise?

    Please select all that apply.
    - Engineering
    - Maintenance

- Safety
- Other (please specify):

3. Mailing address:
4. Do you know other individuals within your agency with centerline rumble strips expertise? If so, please provide their contact information:

For confirmation, this is an installation of centerline rumble strips (source: http://safety.fhwa.dot.gov/):

<u>Centerline Rumble Strips Introduction</u>

5. How prevalent are centerline rumble strips installation in your agency's jurisdiction?

   Please select one.

   - None
   - Rare
   - Occasional
   - Frequent
   - Extensive
   - Uncertain

Centerline Rumble Strips Installation Reasoning

6. Please identify any causal factors your agency is addressing with centerline rumble strips: *Please select all that apply.*
   - ☐ Inattentive or distracted driving
   - ☐ Drowsy driving
   - ☐ Noticeability of centerline in inclement weather conditions
   - ☐ Noticeability of centerline in changes to roadway geometry (e.g. horizontal curvature)
   - ☐ High benefit to cost ratio
   - ☐ Test trial / study / evaluation
   - ☐ Encouragement from FHWA
   - ☐ Uncertain
   - ☐ Other (please specify):
7. Please identify any crash types your agency is addressing with centerline rumble strips:

   Please select all that apply.
   - ☐ Front-end/head-on collisions
   - ☐ Opposite-direction side-swipe collisions
   - ☐ Left-side run-off-the-road collisions
   - ☐ None of the above
   - ☐ Uncertain
   - ☐ Other (please specify):

Centerline Rumble Strips Installation Details

8. What method(s) does your agency utilize to install centerline rumble strips?

   Please select all that apply.
   - ☐ Milled-in (cut into asphalt)

- ☐ Formed (pressed into concrete)
- ☐ Rolled (pressed into hot asphalt)
- ☐ Uncertain
- ☐ Other (please specify):

9. Of the above choices, which, if any, is the predominant installation method of your agency?

   Please select one.

   - Milled-in
   - Formed
   - Rolled
   - No predominant installation method
   - Uncertain
   - Other (please specify):

10. On what type of roadway(s) are your agency's centerline rumble strips installed?

    Please select all that apply.

    - ☐ Rural
    - ☐ Urban
    - ☐ Uncertain
    - ☐ Other (please specify):

11. Does your agency have specifications for centerline rumble strips design and/or placement?

    Please select one.

    - Agency has specifications
    - Agency does not have specifications
    - Uncertain if agency has specifications

Centerline Rumble Strips Issues

12. Has your agency had issues with centerline rumble strips such as (but not limited to):

    Please select one.

    - Accelerated pavement deterioration (e.g. increased cracking)

    - Pavement failure (e.g. section loss)

    - Decreased visibility of paint striping (e.g. sand, decreased retro-reflectivity)

    - Residential issues (e.g. excessive noise)

    - Other adverse issues not listed above

    - Yes
    - No, please skip to question 30.
    - Uncertain

Issue 1: ___________________________

13. Has your agency had issues with **Issue 1** on roadways with centerline rumble strips?

    Please select one.

    - Yes
    - No
    - Uncertain

14. How extensive is **Issue 1** on roadways with centerline rumble strips?

    Please select one.

    - Rare
    - Occasional
    - Frequent
    - Extensive
    - Uncertain

15. On what type of pavement has **Issue 1** occurred?

    Please select all that apply.

    - ☐ Asphalt
    - ☐ Concrete
    - ☐ Uncertain
    - ☐ Other (please specify):

16. What cause(s) has your agency determined for **Issue 1**?

    Please select all that apply.

    - ☐ Age of roadway
    - ☐ Environmental conditions (e.g. freeze/thaw cycle, water ponding, etc.)
    - ☐ Method of centerline rumble strips installation
    - ☐ Method of pavement design or construction
    - ☐ Increased traffic volume
    - ☐ Uncertain at this time

17. What was your agency's response to **Issue 1**? (please select all that apply)

    - Increased maintenance response
    - Resurfaced roadway and reinstalled centerline rumble strips
    - Resurfaced roadway and did not reinstall centerline rumble strips
    - No action taken
    - Uncertain
    - Other (please specify):

18. Please share any additional details you wish to provide regarding **Issue 1:**

Issue 2: ___________________________

19. Has your agency had issues with **Issue 2** on roadways with centerline rumble strips?

    Please select one.

- Yes
- No
- Uncertain

20. How extensive is **Issue 2** on roadways with centerline rumble strips?

    Please select one.

    - Rare
    - Occasional
    - Frequent
    - Extensive
    - Uncertain

21. On what type of pavement has **Issue 2** occurred?

    Please select all that apply.

    - ☐ Asphalt
    - ☐ Concrete
    - ☐ Uncertain
    - ☐ Other (please specify):

22. What cause(s) has your agency determined for **Issue 2**?

    Please select all that apply.

    - ☐ Age of roadway
    - ☐ Environmental conditions (e.g. freeze/thaw cycle, water ponding, etc.)
    - ☐ Method of centerline rumble strips installation
    - ☐ Method of pavement design or construction
    - ☐ Increased traffic volume
    - ☐ Uncertain at this time

23. What was your agency's response to **Issue 2**? (please select all that apply)

    - Increased maintenance response

- Resurfaced roadway and reinstalled centerline rumble strips
- Resurfaced roadway and did not reinstall centerline rumble strips
- No action taken
- Uncertain
- Other (please specify):

Please share any additional details you wish to provide regarding **Issue 2:**

Issue 3: ___________________________

24. Has your agency had issues with **Issue 3** on roadways with centerline rumble strips?

    Please select one.

    - Yes
    - No
    - Uncertain

25. How extensive is **Issue 3** on roadways with centerline rumble strips?

    Please select one.

    - Rare
    - Occasional
    - Frequent
    - Extensive
    - Uncertain

26. On what type of pavement has **Issue 3** occurred?

    Please select all that apply.

    - ☐ Asphalt
    - ☐ Concrete
    - ☐ Uncertain
    - ☐ Other (please specify):

27. What cause(s) has your agency determined for **Issue 3**?

    Please select all that apply.

    - ☐ Age of roadway
    - ☐ Environmental conditions (e.g. freeze/thaw cycle, water ponding, etc.)
    - ☐ Method of centerline rumble strips installation
    - ☐ Method of pavement design or construction
    - ☐ Increased traffic volume
    - ☐ Uncertain at this time

28. What was your agency's response to **Issue 3**? (please select all that apply)

    - Increased maintenance response
    - Resurfaced roadway and reinstalled centerline rumble strips
    - Resurfaced roadway and did not reinstall centerline rumble strips
    - No action taken
    - Uncertain
    - Other (please specify):

Please share any additional details you wish to provide regarding **Issue 3:**

29. If there are additional issues your agency has experienced regarding centerline rumble strips, please briefly describe them below:

<u>Conclusions</u>

30. What is the future of your agency's centerline rumble strips program?

    Please select all that apply.

    - ☐ Considering additional centerline rumble strips
    - ☐ Currently planning additional centerline rumble strips
    - ☐ Constructing centerline rumble strips
    - ☐ Continued upkeep of installed centerline rumble strips

- ☐ Uncertain
- ☐ Other (please specify):

31. What reservations does your agency have in installing additional centerline rumble strips?

    Please select all that apply.

    - ☐ No reservations
    - ☐ Cost of installation
    - ☐ Increased maintenance
    - ☐ Minimal perceived safety benefit
    - ☐ Noise
    - ☐ Environmental considerations (e.g. water ponding)
    - ☐ Uncertain
    - ☐ Other (please specify):

32. What studies has your agency conducted that involves centerline rumble strips?

    Please select all that apply.

    - ☐ Safety
    - ☐ Maintenance
    - ☐ Our agency has not conducted any studies on centerline rumble strips
    - ☐ Uncertain

33. Please leave any additional comments you or your agency has regarding centerline rumble strips:

<u>Thank You</u>

34. May we contact you for additional information or questions regarding your answers?

    Please select one.

    - Yes

- No
- No, please contact this individual (name, title, e-mail, phone number):

35. Would you like to receive a copy of the final report or are you interested in receiving further information?

    Please select one.

    - Yes
    - No

Responses

Table 42: Respondent's Area of Expertise

What is your area of expertise?		
Answer Options	**Response Percent**	**Response Count**
Engineering	89.3%	25
Maintenance	10.7%	3
Safety	42.9%	12
Other (please specify):	10.7%	3
	Responses	***28***

Other (please specify):

- Construction, troubleshooting, pavement evaluations, distress surveys
- Materials
- Pavements and hot mix asphalt materials

•

Table 43: Prevalence of Centerline Rumble Strips in Respondent's Agency

How prevalent are centerline rumble strips installation in your agency's jurisdiction?		
Answer Options	**Response Percent**	**Response Count**
None	0.0%	0
Rare	32.1%	9
Occasional	32.1%	9
Frequent	17.9%	5
Extensive	17.9%	5
Uncertain	0.0%	0
	Responses	***28***

Table 44: Causal Factors Addressed by Centerline Rumble Strips

Please identify any causal factors your agency is addressing with centerline rumble strips:		
Answer Options	**Response Percent**	**Response Count**
Inattentive or distracted driving	85.7%	24
Drowsy driving	82.1%	23
Noticeability of centerline in inclement weather conditions	42.9%	12
Noticeability of centerline in changes to roadway geometry (e.g., horizontal curvature)	28.6%	8
High benefit to cost ratio	50.0%	14
Test trial / study / evaluation	39.3%	11
Encouragement from FHWA	25.0%	7
Uncertain	3.6%	1
Other (please specify):	14.3%	4

Other (please specify):

- Volume thresholds are part of the criteria for this transportation agency. It is generally held that there is not a lower cost alternative for preventing cross-centerline lane departure crashes, and is justified to address the random occurrence of this type of crash.
- Lane departures.

- This agency has been trying to address areas where there are high accident rates and the likelihood of vehicles crossing centerline is more prominent and leading to accidents. This agency's terrain is varied with low lying areas along rivers and high, hilly, mountainous terrain, both of which are subject to limited visibility due to heavy fog conditions and/or limited sight distance. The installation of centerline rumble strips has helped with driver awareness as vehicles navigate these locations.
- This agency was an early adopter of centerline rumble strips; centerline rumble strips have proven to be a cost effective tool.

Table 45: Crash Types Addressed by Centerline Rumble Strips

Please identify any crash types your agency is addressing with centerline rumble strips:		
Answer Options	**Response Percent**	**Response Count**
Front-end / head-on collisions	92.9%	26
Opposite-direction side-swipe collisions	82.1%	23
Left-side run-off-the-road collisions	60.7%	17
None of the above	0.0%	0
Uncertain	3.6%	1
Other (please specify);	3.6%	1

Other (please specify):

- Systematic approach to improve safety.

Table 46: Methods Used to Install Centerline Rumble Strips

What method(s) does your agency utilize to install centerline rumble strips?		
Answer Options	**Response Percent**	**Response Count**
Milled-in (cut into asphalt)	100.0%	28
Formed (pressed into concrete)	3.6%	1
Rolled (pressed into hot asphalt)	3.6%	1
Uncertain	0.0%	0
Other (please specify):	7.1%	2

Other (please specify):

- Milled-in into concrete as well.
- Previously used rolled but not any longer.

Table 47: Predominant Installation Method of Centerline Rumble Strips

Of the above choices, which, if any, is the predominant installation method of your agency?		
Answer Options	Response Percent	Response Count
Milled-in (cut into asphalt)	96.4%	27
Formed (pressed into concrete)	0.0%	0
Rolled (pressed into hot asphalt)	0.0%	0
No predominant installation method	3.6%	1
Uncertain	0.0%	0
Other (please specify):	0.0%	0

Table 48: Roadway Types of Centerline Rumble Strips Installation

On what type of roadway(s) are your agency's centerline rumble strips installed?		
Answer Options	**Response Percent**	**Response Count**
Rural	96.4%	27
Urban	17.9%	5
Uncertain	0.0%	0
Other (please specify):	10.7%	3

Other (please specify):

- This agency has installed centerline rumble strips outside of incorporated city limits.
- This agency has published guidelines that direct the installation towards areas that are not built up and have lower housing densities.
- This agency is installing centerline rumble strips on roadways with speed limits of 50 mph or greater. If the roadway is in an urbanized area, centerline rumble strips are only placed based on crash analyses.

Table 49: Existence of Specifications for Centerline Rumble Strips Design and/or Placement

Does your agency have specifications for centerline rumble strips design and/or placement?		
Answer Options	**Response Percent**	**Response Count**
Agency has specifications	89.3%	25
Agency does not have specifications	10.7%	3
Uncertain if agency has specifications	0.0%	0

Table 50: Presence of Issues Associated with Centerline Rumble Strips

Has your agency had issues with centerline rumble strips such as (but not limited to): **- Accelerated pavement deterioration (e.g., increased cracking)** **- Pavement failure (e.g., section loss)** **- Decreased visibility of paint striping (e.g., sand, decreased retro-reflectivity)** **- Residential issues (e.g., excessive noise)** **- Other adverse issues not listed above**		
Answer Options	**Response Percent**	**Response Count**
Yes	35.7%	10
No	32.1%	9
Uncertain	32.1%	9

Accelerated Pavement Deterioration

Table 51: Presence of Accelerated Pavement Deterioration Issues

Has your agency had issues with accelerated pavement deterioration?		
Answer Options	**Response Percent**	**Response Count**
Yes	50.0%	5
No	40.0%	4
Uncertain	10.0%	1

Table 52: Extensiveness of Accelerated Pavement Deterioration

How extensive is accelerated pavement deterioration?		
Answer Options	**Response Percent**	**Response Count**
Rare	20.0%	1
Occasional	60.0%	3
Frequent	0.0%	0
Extensive	0.0%	0
Uncertain	20.0%	1

Table 53: Pavement Type on Which Accelerated Pavement Deterioration Occurred

On what type of pavement has accelerated pavement deterioration occurred?		
Answer Options	**Response Percent**	**Response Count**
Asphalt	80.0%	4
Concrete	20.0%	1
Uncertain	0.0%	0
Other (please specify)	40.0%	2

Other (please specify):

- Asphalt with chip seal

- Bituminous surface treatment routes with AADTs below 5,000

Table 54: Causes Agency Has Determined for Accelerated Pavement Deterioration

What causes has your agency determined for accelerated pavement deterioration?		
Answer Options	**Response Percent**	**Response Count**
Age of roadway	80.0%	4
Environmental conditions	40.0%	2
Method of CLRS installation	20.0%	1
Method of pavement design	20.0%	1
Increased traffic volume	0.0%	0
Uncertain at this time	20.0%	1
Other (please specify):	60.0%	3

Other (please specify):

- This agency has general issues with centerline joint deterioration that is generally held as a flaw in its construction process
- Most damage is caused by milling rumble strips into an older pavement, which leads to raveling and joint damage in hot mix asphalt and joint spalling in Portland cement concrete. There was one hot mix asphalt project that the mill head damaged the surface by peeling out the pavement in the heat of summer (100+ °F).
- Several issues appear to partly contribute to this problem. This agency's issues were primarily related to recessed pavement markers used in conjunction with milled-in rumble strips. This agency is seeing some "trenching" along the centerline rumble strips installations. Installation error in some cases with raised pavement markers being ground through rumbles or vice versa. Other issues may relate to asphalt binders and environmental conditions.

Table 55: Agency's Response to Accelerated Pavement Deterioration

What was your agency's response to accelerated pavement deterioration?		
Answer Options	**Response Percent**	**Response Count**
Increased maintenance response	40.0%	2
Resurfaced roadway and reinstalled CLRS	40.0%	2
Resurfaced roadway and did not reinstall CLRS	20.0%	1
No action taken	20.0%	1
Uncertain	40.0%	2
Other (please specify):	20.0%	1

Other (please specify):

- Centerline joint repair and reinstallation of centerline rumble strips.

Please share any additional issues you wish to provide regarding accelerated pavement deterioration.

- This agency currently uses dual, 8-inch rumble strips that straddle the centerline joint (2-inches on each side, 4-inches total between strips). The close proximity to the joint is a contributing factor to the damage. However, this agency is reluctant to change the design due to limited research.
- The failures this agency has seen have occurred on pavements which were several years old when the centerline rumble strips were milled in. This agency has not seen issues with centerline rumble strips installed into new pavements. However, all of these installations were fairly recent. This agency does have concerns with water ponding in the grooves and placing additional freeze/thaw stress on the joint. It will be watching this closely.

Pavement Failure

Table 56: Presence of Pavement Failure Issues

Has your agency had issues with pavement failure?		
Answer Options	**Response Percent**	**Response Count**
Yes	30.0%	3
No	70.0%	7
Uncertain	10.0%	1

Table 57: Extensiveness of Pavement Failure

How extensive is pavement failure?		
Answer Options	**Response Percent**	**Response Count**
Rare	100.0%	3
Occasional	0.0%	0
Frequent	0.0%	0
Extensive	0.0%	0
Uncertain	0.0%	0

Table 58: Pavement Type on Which Pavement Failure Occurred

On what type of pavement has pavement failure occurred?		
Answer Options	**Response Percent**	**Response Count**
Asphalt	66.7%	2
Concrete	0.0%	0
Uncertain	0.0%	0
Other (please specify)	33.3%	1

Other (please specify):

- Multiple lifts of bituminous surface treatment and milled through roadbed at a few locations on a single mountainous recreational route.

Table 59: Causes Agency Has Determined for Pavement Failure

What causes has your agency determined for pavement failure?		
Answer Options	**Response Percent**	**Response Count**
Age of roadway	66.7%	2
Environmental conditions	33.3%	1
Method of CLRS installation	33.3%	1
Method of pavement design	33.3%	1
Increased traffic volume	0.0%	0
Uncertain at this time	0.0%	0
Other (please specify):	0.0%	0

Table 60: Agency's Response to Pavement Failure

What was your agency's response to accelerated pavement deterioration?		
Answer Options	**Response Percent**	**Response Count**
Increased maintenance response	33.3%	1
Resurfaced roadway and reinstalled CLRS	66.7%	2
Resurfaced roadway and did not reinstall CLRS	33.3%	1
No action taken	0.0%	0
Uncertain	0.0%	0
Other (please specify):	0.0%	0

Please share any additional issues you wish to provide regarding pavement failure.

- There was a crash history on a segment of roadway in this agency but resurfacing dollars were not immediately available. The centerline rumble strips were milled in and the centerline joint broke apart. This agency is currently specifying joint adhesive during the paving process.

Decreased Visibility of Paint Striping

Table 61: Presence of Decreased Visibility of Paint Striping

Has your agency had issues with decreased visibility of paint striping?		
Answer Options	**Response Percent**	**Response Count**
Yes	10.0%	1
No	90.0%	9
Uncertain	10.0%	1

Table 62: Extensiveness of Decreased Visibility of Paint Striping

How extensive is decreased visibility of paint striping?		
Answer Options	**Response Percent**	**Response Count**
Rare	100.0%	1
Occasional	0.0%	0
Frequent	0.0%	0
Extensive	0.0%	0
Uncertain	0.0%	0

Table 63: Pavement Type on Which Decreased Visibility of Paint Striping Occurred

On what type of pavement has decreased visibility of paint striping occurred?		
Answer Options	**Response Percent**	**Response Count**
Asphalt	100.0%	1
Concrete	0.0%	0
Uncertain	0.0%	0
Other (please specify)	0.0%	0

Table 64: Causes Agency Has Determined for Decreased Visibility of Paint Striping

What causes has your agency determined for decreased visibility of paint striping?		
Answer Options	**Response Percent**	**Response Count**
Age of roadway	100.0%	1
Environmental conditions	0.0%	0
Method of CLRS installation	0.0%	0
Method of pavement design	0.0%	0
Increased traffic volume	0.0%	0
Uncertain at this time	0.0%	0
Other (please specify):	0.0%	0

Table 65: Agency's Response to Decreased Visibility of Paint Striping

What was your agency’s response to decreased visibility of paint striping?		
Answer Options	**Response Percent**	**Response Count**
Increased maintenance response	100.0%	1
Resurfaced roadway and reinstalled CLRS	0.0%	0
Resurfaced roadway and did not reinstall CLRS	0.0%	0
No action taken	0.0%	0
Uncertain	0.0%	0
Other (please specify):	0.0%	0

Please share any additional issues you wish to provide regarding decreased visibility of paint striping.

Residential Issues

Table 66: Presence of Residential Issues

Has your agency had residential issues?		
Answer Options	**Response Percent**	**Response Count**
Yes	70.0%	7
No	20.0%	2
Uncertain	10.0%	1

Table 67: Extensiveness of Residential Issues

How extensive are residential issues?		
Answer Options	**Response Percent**	**Response Count**
Rare	28.6%	2
Occasional	71.4%	5
Frequent	0.0%	0
Extensive	0.0%	0
Uncertain	0.0%	0

Table 68: Pavement Type on Which Residential Issues Occurred

On what type of pavement has residential issues occurred?		
Answer Options	**Response Percent**	**Response Count**
Asphalt	85.7%	6
Concrete	0.0%	0
Uncertain	14.3%	1
Other (please specify)	14.3%	1

Other (please specify):

- Bituminous surface treated roadways.

Table 69: Causes Agency Has Determined for Residential Issues

What causes has your agency determined for residential issues?		
Answer Options	**Response Percent**	**Response Count**
Age of roadway	0.0%	0
Environmental conditions	0.0%	0
Method of CLRS installation	0.0%	0
Method of pavement design	0.0%	0
Increased traffic volume	14.3%	1
Uncertain at this time	14.3%	1
Other (please specify):	85.7%	6

Other (please specify):

- The newness of the rumble strips in an environment is the most frequent issue. Calls of complaints subside in 2-3 months after installation.
- A few noise complaints would be reported regardless of pavement condition, type, etc.
- Noise from vehicles passing in locations with centerline rumble strips.
- Most often in passing areas or horizontal curves.
- The presence of rumble strips in rural residential areas.
- Noise complaints.

Table 70: Agency's Response to Residential Issues

What was your agency's response to residential issues?		
Answer Options	**Response Percent**	**Response Count**
Increased maintenance response	0.0%	0
Resurfaced roadway and reinstalled CLRS	0.0%	0
Resurfaced roadway and did not reinstall CLRS	0.0%	0
No action taken	57.1%	4
Uncertain	0.0%	0
Other (please specify):	57.1%	4

Other (please specify):

- Explained to the concerned parties the safety benefits of centerline rumble strips.
- Refined installation policy to identify "suburban" locations where the population was greater than typical rural areas.
- Exterior and interior vehicle noise studies; examined possibilities for restriping, removing, and re-milling centerline rumble strips.
- Depending on the situation, sometimes breaks were placed in the pattern or left alone.

Please share any additional issues you wish to provide regarding residential issues.

- Noise issues arise occasionally. This agency verifies the installation is to its standard. If the centerline rumble strips are too deep or installed in locations that will be hit inadvertently (other than in passing zones), this agency has made adjustments.

Other Adverse Issues

Table 71: Presence of Additional Adverse Issues

Has your agency had issues with other adverse issues?		
Answer Options	**Response Percent**	**Response Count**
Yes	10.0%	1
No	90.0%	9
Uncertain	10.0%	1

This was an open-ended question. One agency remarked that it had issues regarding the shying away of motorists from the centerline on rural routes due to centerline rumble strips, which resulted in pavement edge and shoulder damage.

Table 72: Extensiveness of Driving Behavior Change

How extensive is driving behavior change?		
Answer Options	**Response Percent**	**Response Count**
Rare	0.0%	0
Occasional	0.0%	0
Frequent	100.0%	1
Extensive	0.0%	0
Uncertain	0.0%	0

Table 73: Pavement Type on Which Driving Behavior Change Occurred

On what type of pavement has driving behavior change occurred?		
Answer Options	**Response Percent**	**Response Count**
Asphalt	100.0%	1
Concrete	0.0%	0
Uncertain	0.0%	0
Other (please specify)	0.0%	0

Table 74: Causes Agency Has Determined for Driving Behavior Change

What causes has your agency determined for driving behavior change?		
Answer Options	**Response Percent**	**Response Count**
Age of roadway	0.0%	0
Environmental conditions	0.0%	0
Method of CLRS installation	0.0%	0
Method of pavement design	0.0%	0
Increased traffic volume	100.0%	1
Uncertain at this time	0.0%	0
Other (please specify):	100.0%	1

Other (please specify):

- Lane width.

Table 75: Agency's Response to Driving Behavior Change

What was your agency's response to driving behavior change?		
Answer Options	**Response Percent**	**Response Count**
Increased maintenance response	0.0%	0
Resurfaced roadway and reinstalled CLRS	0.0%	0
Resurfaced roadway and did not reinstall CLRS	0.0%	0
No action taken	0.0%	0
Uncertain	0.0%	0
Other (please specify):	100.0%	1

Other (please specify):

- Widened shoulder.

Please share any additional issues you wish to provide regarding driving behavior change.

Table 76: Future of Agency's Centerline Rumble Strips Program

What is the future of your agency's centerline rumble strips program?		
Answer Options	**Response Percent**	**Response Count**
Considering additional centerline rumble strips	28.6%	8
Currently planning additional centerline rumble strips installation	42.9%	12
Constructing centerline rumble strips	75.0%	21
Continued upkeep of installed centerline rumble strips	25.0%	7
Uncertain	3.6%	1
Other (please specify):	17.9%	5

Other (please specify):

- This agency is developing a design for use that reduces the concern of water ponding and freezing.
- This agency is planning to use centerline rumble strips on a more systematic basis across its state highway network.
- This agency is trying to be selective and using centerline rumble strips where they would get the most benefit. It is concerned about the potential for increase in rate of pavement deterioration. However, this agency has taken great steps to improve its longitudinal joint density so it hopes it does not see advanced deterioration. This agency has only placed centerline rumble strips for two years, so it does not have enough time to fully answer this. However, this agency is pleased with the use so far.
- Centerline rumble strips are considered in high cross-over or run-off-the-road to the left crash locations on a case by case basis.

- This agency has just completed design of a project that will install centerline rumble strips at five locations on state roads beginning in the spring of 2013. Up until now, there have not been additional installations.

Table 77: Reservations in Installing Centerline Rumble Strips

What reservations does your agency have in installing additional centerline rumble strips?		
Answer Options	**Response Percent**	**Response Count**
No reservations	25.0%	7
Cost of installation	3.6%	1
Increased maintenance	25.0%	7
Minimal perceived safety benefit	3.6%	1
Noise	57.1%	16
Environmental considerations (e.g., water ponding)	17.9%	5
Uncertain	0.0%	0
Other (please specify)	25.0%	7

Other (please specify):

- Centerline rumble strips force cars to the outside of the lane
- The combination of centerline and edgeline rumble strips
- Overall complaints
- This agency has not had huge concerns about the longevity of the pavement but noise has been the overwhelming source of issues on its current installations.
- Potential increase in rate of pavement deterioration.
- Small diameter tire vibration during passing.
- Adverse effects towards motorcyclists.
- The main concern for this agency is the effect of centerline rumble strips on asphalt pavement. Since the longitudinal joint is located in the center of the pavement, its concern is the effect of milling at the joint.

- There have not been significant maintenance issues with rumble trips installation with this agency. Noise is a concern and this agency's policy guidance encourages installations which have breaks where automobiles make turning movements. Efforts are underway to test alternative depths and grind patterns to minimize audible noise outside the vehicle.

Table 78: Studies Agency has Conducted Involving Centerline Rumble Strips

What studies has your agency conducted that involve centerline rumble strips?		
Answer Options	**Response Percent**	**Response Count**
Safety	50.0%	14
Maintenance	17.9%	5
Our agency has not conducted any studies on centerline rumble strips	35.7%	10
Uncertain	10.7%	3

Table 79: Opportunity for Additional Information Regarding Centerline Rumble Strips

May we contact you for additional information or questions regarding your answers?		
Answer Options	**Response Percent**	**Response Count**
Yes	96.4%	27
No	0.0%	0
No, please contact this individual	3.6%	1

Table 80: Desire for Respondent to Receive a Copy of This Report

Would you like to receive a copy of the final report or are you interested in receiving further information?		
Answer Options	**Response Percent**	**Response Count**
Yes	96.4%	27
No	3.4%	1

Additional Comments

- This agency's oldest centerline rumble strips have not been in place for too long so it do not have long term experience with pavement distress. This agency did look at crash reduction in the corridors where they have been installed.
- This agency has only placed centerline rumble strips over the past two to three years. Responses have been positive from motorists and internal personnel. It has definitely forced drivers to not cross over the centerline as often as they normally would. Evaluation is still on going.
- An independent organization is currently studying this agency's centerline rumble strips program, which were mostly installed after the awarding of a Rural Safety Innovation Program Grant.
- This agency has some concern with milling over joints. No definite conclusion on whether or not it speeds deterioration. Glad to see this is being investigated.
- Currently this agency has constructed centerline rumble strips at two specific locations that were targeted for their use. It is in the process of developing standards which include details, specifications and design guidance for their use. This agency expects this to be in place in the fall of 2013. At that time, centerline rumble strips will be specified as a standard on all construction projects with particular roadway characteristics. The questions answered in this survey were based on this agency's current very limited use of centerline rumble strips at only two locations. Any information received relative to pavement performance will be forwarded to our Pavement Management Bureau identified earlier.
- Centerline rumble strips were installed on a 0.6 mile section of a route in 1999 but were removed in 2000 due to noise complaints. This agency has not installed centerline rumble strips on state roads since then. This agency will have additional installations beginning in 2014.

- This agency is observing the maintenance issue and effect, if any, on kits experimental project locations.
- This agency, as an early adopter of centerline rumble strips, presented data from its installations to a study by the Insurance Institute for Highway Safety.

APPENDIX B

SITE CHARACTERISTICS

Characteristics pertaining to each of the 10 centerline rumble strips installation site are detailed in this appendix. The order in which the sites are presented is first by project ID number and second by State Route number if the project contained more than one section of roadway with centerline rumble strips. Each site contains information obtained from GDOT, the study beginning and ending mileposts, a map overview, Google Street View screenshots detailing the extent of the centerline rumble strips' installation, and basic before and after crash statistics.

In Georgia, GDOT implemented seven projects which installed centerline rumble strips. The combined total mileage of roadways with centerline rumble strips on these 10 sites is about 126-miles. The 10 installation sites, indicated with a blue X are spread throughout 12 counties, highlighted in yellow, as seen in Figure 40.

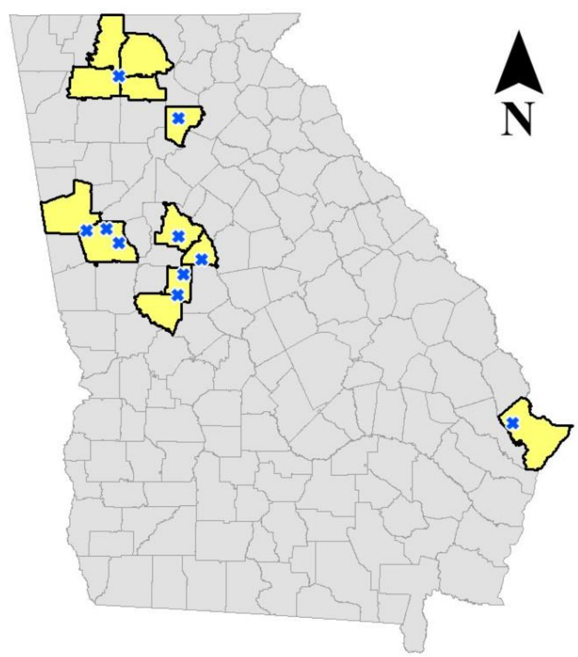


Figure 40: Centerline Rumble Strips Installation Sites in Georgia

Project ID: 0006693, SR 14

Figure 41: Project 0006693, SR 14 Details (clockwise from top left): Map [14], Location within Georgia, MP 21 Facing South [15], MP 27 Facing North [15]

Table 81: Project 0006693, SR 14, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006693
	Project Number	CSSTP-0006-00(693)
	Project Title	SR 14|SR 16|SR 154@SEV LOC IN CARROLL&COWETA [CENTERLINE]
	Management Let	6/17/2005
	Project Completion	4/26/2006
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3, 6
	Congressional District	3
	Project Description	SR 14 from Herring Road/CR 43 to Johnston Circle/CR 7 (approximately 6.5 miles in Coweta County)
	Construction Contractor	JHC Corporation
	MPO	Atlanta TMA, Not Urban
Federal Report of Completed Projects	Construction Begin Date	10/11/2005
	Time Charges Stop Date	10/31/2005

Table 82: Project 0006693, SR 14, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 14
Beginning Milepost	19.68
Ending Milepost	27.55
County (Begin)	Coweta
County (End)	Coweta
Length (mi)	7.87
RCLINK	0771001400
Beginning Coordinates	33.436426,-84.750488
Ending Coordinates	33.50653,-84.671309
AADT MP 18.06 – 19.74	2003 – 10,970 2004 – 10,970 2007 – 10,430 2008 – 10,110
AADT MP 19.74 – 23.16	2003 – 14,240 2004 – 14,240 2007 – 14,120 2008 – 12,580
AADT MP 23.17 – 26.71	2003 – 8,660 2004 – 8,660 2007 – 8,700 2008 – 8,210
AADT MP 26.72 – 27.62	2003 – 9,090 2004 – 9,090 2007 – 9,310 2008 – 9,490

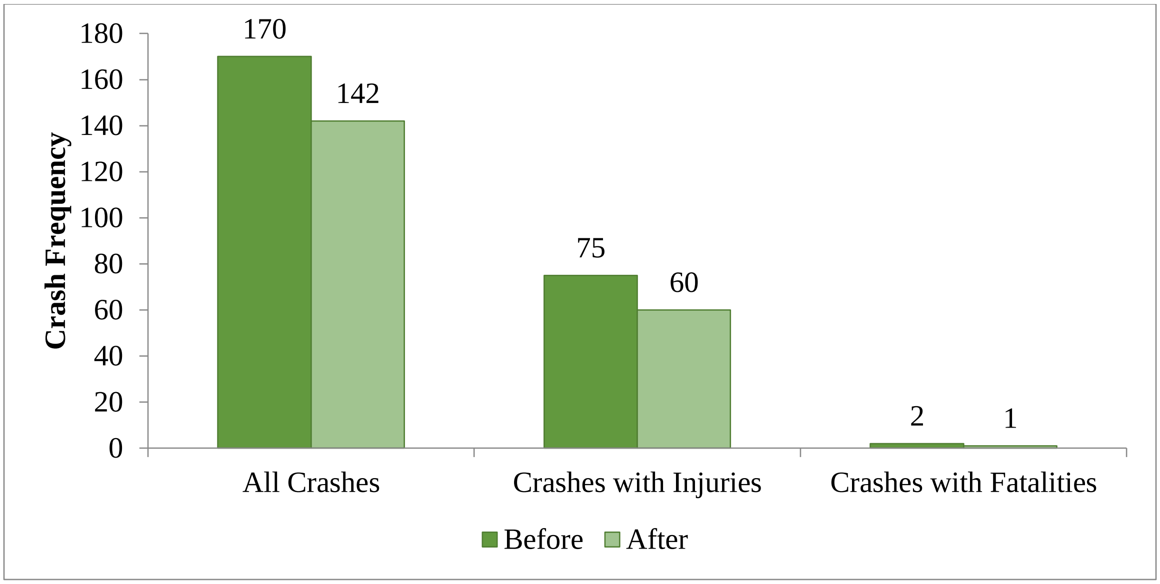


Figure 42: Project 0006693, SR 14, Before and After Crash Frequencies

Project ID: 0006693, SR 16

Figure 43: Project 0006693, SR 16 Details (clockwise from top left): Map [14], Location within Georgia, MP 6 Facing North [15], MP 17 Facing South [15]

Table 83: Project 0006693, SR 16, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006693
	Project Number	CSSTP-0006-00(693)
	Project Title	SR 14|SR 16|SR 154@SEV LOC IN CARROLL&COWETA [CENTERLINE]
	Management Let	6/17/2005
	Project Completion	4/26/2006
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3, 6
	Congressional District	3
	Project Description	SR 16/US 27 from the Carrollton Bypass to the Newnan Bypass (approximately 17 miles in Carroll and Coweta Counties)
	Construction Contractor	JHC Corporation
	MPO	Atlanta TMA, Not Urban
Federal Report of Completed Projects	Construction Begin Date	10/11/2005
	Time Charges Stop Date	10/31/2005

Table 84: Project 0006693, SR 16, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 16
Beginning Milepost	16.69
Ending Milepost	7.06
County (Begin)	Carroll
County (End)	Coweta
Length (mi)	18.09
RCLINK	0451001600 0771001600
Beginning Coordinates	33.567596,-85.047001
Ending Coordinates	33.397675,-84.82808
AADT MP 16.56 – 18.03 (Carroll County)	2003 – 12,540 2004 – 12,540 2007 – 12,120 2008 – 11,750
AADT MP 18.03 – 23.08 (Carroll County)	2003 – 10,970 2004 – 10,970 2007 – 11,520 2008 – 10,270
AADT MP 23.08 – 26.18 (Carroll County)	2003 – 11,520 2004 – 11,520 2007 – 10,040 2008 – 9,660
AADT MP 26.19 – 27.87 (Carroll County)	2003 – 8,920 2004 – 8,920 2007 – 8,390 2008 – 9,070
AADT MP 0.00 – 3.85 (Coweta County)	2003 – 7,590 2004 – 7,590 2007 – 8,320 2008 – 7,280
AADT MP 3.86 – 6.32 (Coweta County)	2003 – 9,920 2004 – 9,780 2007 – 9,330 2008 – 8,980

Table 84 Continued on Next Page

Table 84 Continued

Attribute	Detail
AADT MP 6.33 – 6.97 (Coweta County)	2003 – 10,760 2004 – 12,580 2007 – 11,810 2008 – 10,720

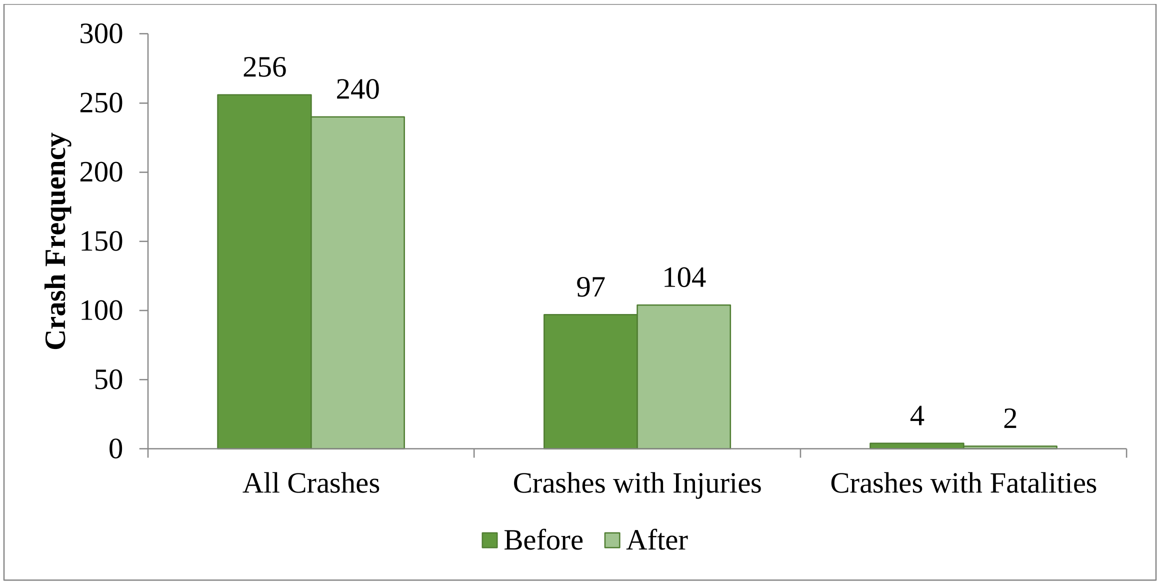


Figure 44: Project 0006693, SR 16, Before and After Crash Frequencies

Project ID: 0006693, SR 154

Figure 45: Project 0006693, SR 154 Details (clockwise from top left): Map [14], Location within Georgia, MP 7 Facing North [15], MP 0.20 Facing North [15]

Table 85: Project 0006693, SR 154, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006693
	Project Number	CSSTP-0006-00(693)
	Project Title	SR 14|SR 16|SR 154@SEV LOC IN CARROLL&COWETA [CENTERLINE]
	Management Let	6/17/2005
	Project Completion	4/26/2006
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3, 6
	Congressional District	3
	Project Description	This project consists of installing ground-in rumble strips along the centerline of the following routes: SR 154 from SR 54 in Sharpsburg to I-85 (approximately 6 miles in Coweta County).
	Construction Contractor	JHC Corporation
	MPO	Atlanta TMA, Not Urban
Federal Report of Completed Projects	Construction Begin Date	10/11/2005
	Time Charges Stop Date	10/31/2005

Table 86: Project 0006693, SR 154, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 154
Beginning Milepost	0.11
Ending Milepost	7.60
County (Begin)	Coweta
County (End)	Coweta
Length (mi)	7.60
RCLINK	0771015400
Beginning Coordinates	33.341985,-84.647195
Ending Coordinates	33.43996,-84.691777
AADT MP 0.00 – 0.56	2003 – 5,700 2004 – 5,700 2007 – 6,080 2008 – 5,930
AADT MP 0.56 – 3.33	2003 – 7,800 2004 – 7,800 2007 – 12,170 2008 – 11,860
AADT MP 3.34 – 5.30	2003 – 11,840 2004 – 12,410 2007 – 12,870 2008 – 12,720
AADT MP 5.31 – 7.91	2003 – 13,620 2004 – 13,620 2007 – 15,380 2008 – 14,990

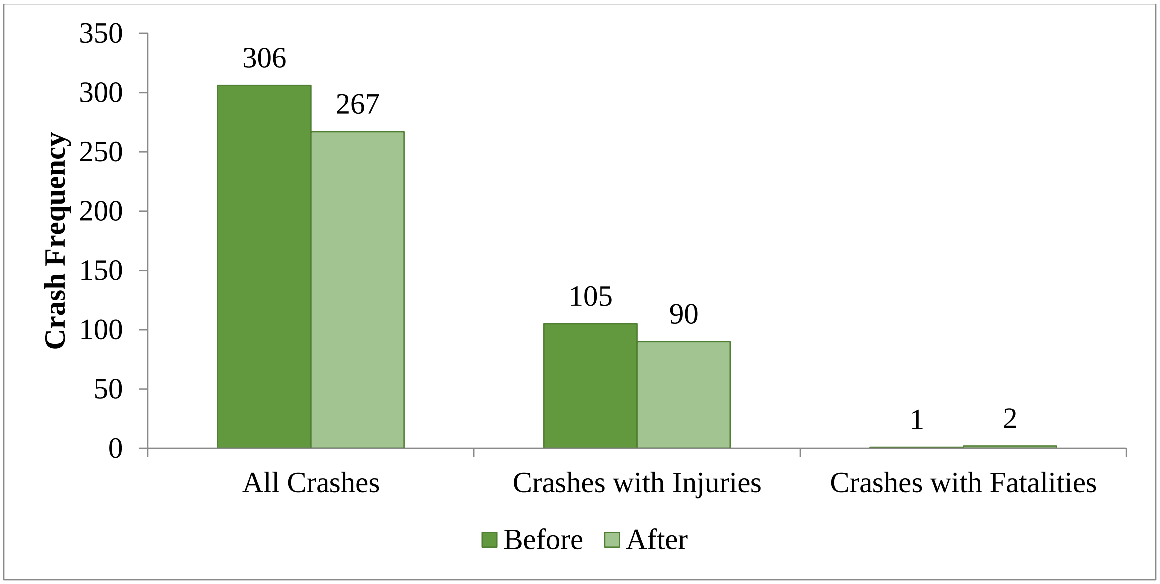


Figure 46: Project 0006693, SR 154, Before and After Crash Frequencies

Project ID: 0006945, SR 369

Figure 47: Project 0006945, SR 369 Details (clockwise from top left): Map [14], Location within Georgia, MP 10 Facing East [15], MP 1 Facing East [15]

Table 87: Project 0006945, SR 369, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006945
	Project Number	CSSTP-0006-00(945)
	Project Title	SR 369 FM CHEROKEE CO TO HALL CO - CENTERLINE RUMBLE STRIPS
	Management Let	6/17/2005
	Project Completion	4/26/2006
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	1
	Congressional District	9
	Project Description	Indentation centerline rumble strips on SR 369 in Forsyth County in District 1
	Construction Contractor	Peek Pavement Marking, LLC
	MPO	Atlanta TMA
Federal Report of Completed Projects	Construction Begin Date	3/6/2006
	Time Charges Stop Date	3/26/2006

Table 88: Project 0006945, SR 369, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 369
Beginning Milepost	0.00
Ending Milepost	19.89
County (Begin)	Forsyth
County (End)	Forsyth
Length (mi)	19.89
RCLINK	1171036900
Beginning Coordinates	34.295106,-84.258292
Ending Coordinates	34.262606,-83.95333
AADT MP 0.00 – 2.70	2003 – 7,650 2004 – 7,650 2007 – 7,730 2008 – 7,360
AADT MP 2.70 – 5.79	2003 – 10,040 2004 – 10,040 2007 – 9,790 2008 – 9,290
AADT MP 5.80 – 6.42	2003 – 14,310 2004 – 14,310 2007 – 13,990 2008 – 13,310
AADT MP 6.43 – 10.06	2003 – 14,450 2004 – 14,450 2007 – 12,970 2008 – 12,950
AADT MP 10.07 – 11.07	2003 – 18,380 2004 – 18,380 2007 – 18,510 2008 – 17,620
AADT MP 11.08 – 11.85	2003 – 12,630 2004 – 12,630 2007 – 12,900 2008 – 12,030
AADT MP 11.86 – 12.81	2003 – 23,640 2004 – 23,640 2007 – 20,420 2008 – 19,430

AADT MP 12.82 – 19.89	2003 – 15,660 2004 – 15,660 2007 – 15,960 2008 – 13,960

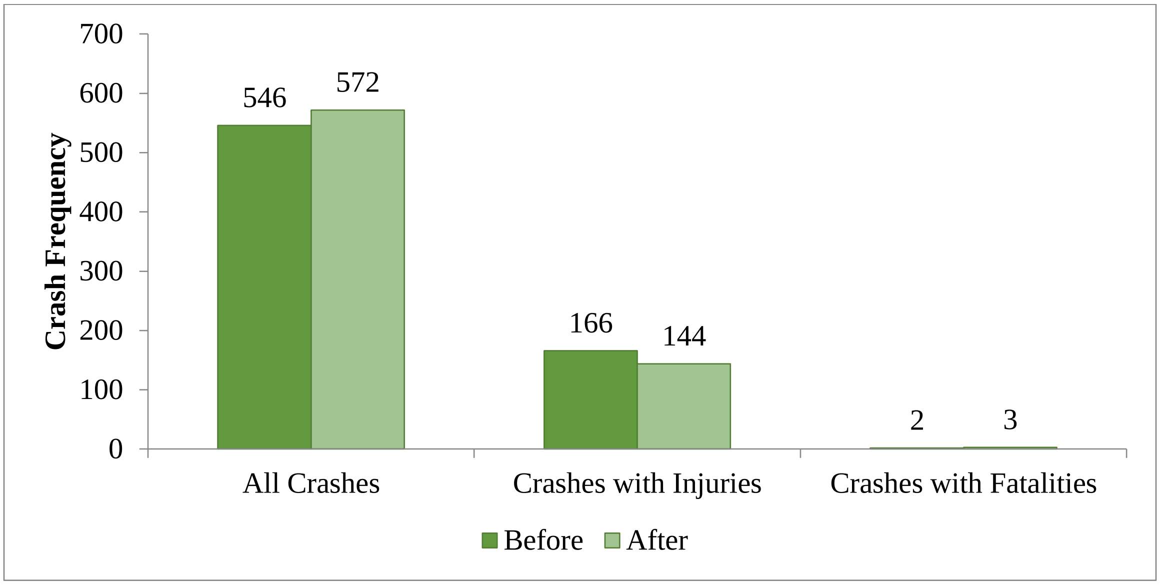


Figure 48: Project 0006945, SR 369 Before and After Crash Frequencies

Project ID: 0006975, SR 42 Section A

Figure 49: Project 0006975, SR 42, Section A Details (clockwise from top left): Map [14], Location within Georgia, MP 7 Facing South [15], MP 3 Facing South [15]

Table 89: Project 0006975, SR 42, Section A, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006975
	Project Number	CSSTP-0006-00(975)
	Project Title	SR 42@SEV LOC IN HENRY|BUTTS|MONROE-CENTERLINE RUMBLE STRIPS
	Management Let	8/19/2005
	Project Completion	12/3/2009
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3
	Congressional District	3, 8
	Project Description	Indentation centerline rumble strips on SR 42 at several locations in Henry, Butts, and Monroe Counties in District 3
	Construction Contractor	-
	MPO	Atlanta TMA, Not Urban
Federal Report of Completed Projects	Construction Begin Date	1/17/2006
	Time Charges Stop Date	5/31/2006

Table 90: Project 0006975, SR 42, Section A, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 42
Beginning Milepost	0.00
Ending Milepost	7.97
County (Begin)	Butts
County (End)	Butts
Length (mi)	7.97
RCLINK	0351004200
Beginning Coordinates	33.201781,-83.936577
Ending Coordinates	33.290544,-83.950943
AADT MP 0.00 – 3.01	2003 – 1,440 2004 – 1,440 2007 – 1,360 2008 – 1,540
AADT MP 3.18 – 4.80	2003 – 2,590 2004 – 2,590 2007 – 3,080 2008 – 2,930
AADT MP 4.81 – 7.43	2003 – 6,340 2004 – 6,340 2007 – 6,120 2008 – 5,430
AADT MP 7.44 – 7.67	2003 – 8,380 2004 – 8,380 2007 – 8,200 2008 – 7,890

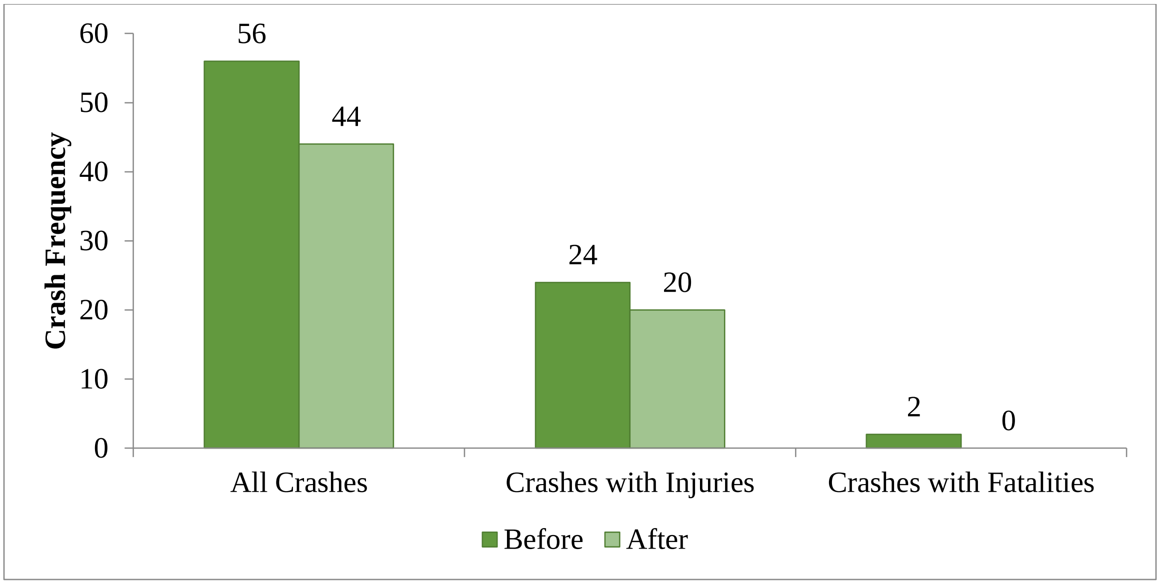


Figure 50: Project 0006975, SR 42, Section A Before and After Crash Frequencies

Project ID: 0006975, SR 42 Section B

Figure 51: Project 0006975, SR 42, Section B Details (clockwise from top left): Map [14], Location within Georgia, MP 8 Facing North [15], MP 5 Facing North [15]

Table 91: Project 0006975, SR 42, Section B, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006975
	Project Number	CSSTP-0006-00(975)
	Project Title	SR 42@SEV LOC IN HENRY|BUTTS|MONROE- CENTERLINE RUMBLE STRIPS
	Management Let	8/19/2005
	Project Completion	12/3/2009
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3
	Congressional District	3, 8
	Project Description	Indentation centerline rumble strips on SR 42 at several locations in Henry, Butts, and Monroe Counties in District 3
	Construction Contractor	-
	MPO	Atlanta TMA, Not Urban
Federal Report of Completed Projects	Construction Begin Date	1/17/2006
	Time Charges Stop Date	5/31/2006

Table 92: Project 0006975, SR 42, Section B, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 42
Beginning Milepost	4.58
Ending Milepost	9.81
County (Begin)	Henry
County (End)	Henry
Length (mi)	5.23
RCLINK	1511004200
Beginning Coordinates	33.354986,-84.114869
Ending Coordinates	33.424601,-84.143735
AADT MP 4.48 – 8.52	2003 – 10,160 2004 – 10,160 2007 – 11,700 2008 – 11,260
AADT MP 8.53 – 9.95	2003 – 7,480 2004 – 7,480 2007 – 8,290 2008 – 8,160

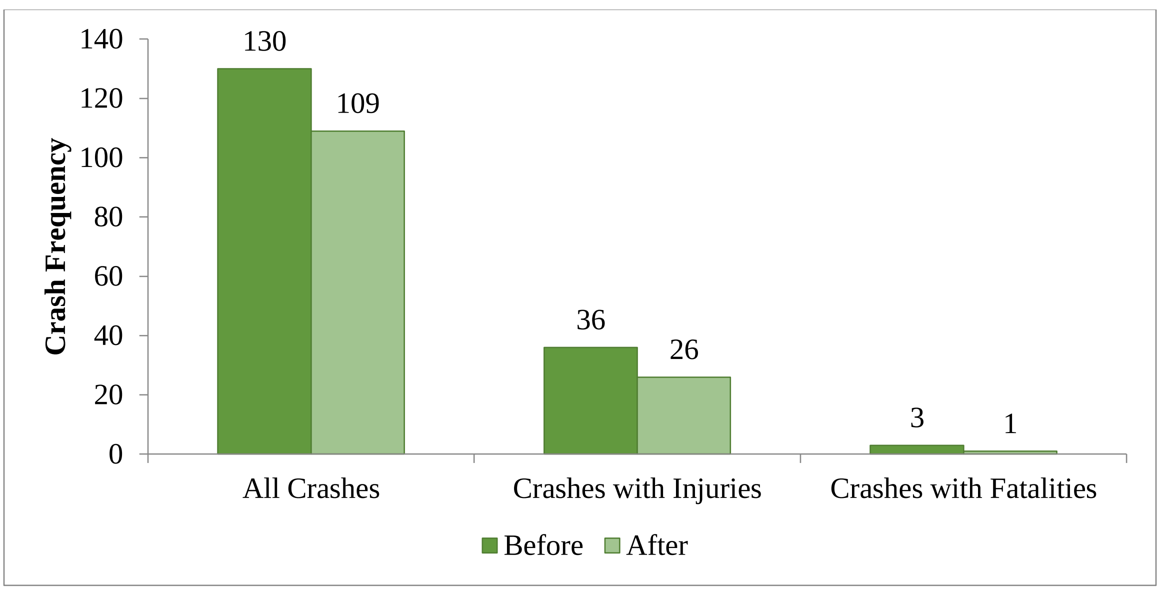


Figure 52: Project 0006975, SR 42, Section B, Before and After Crash Frequencies

Project ID: 0006976, SR 204

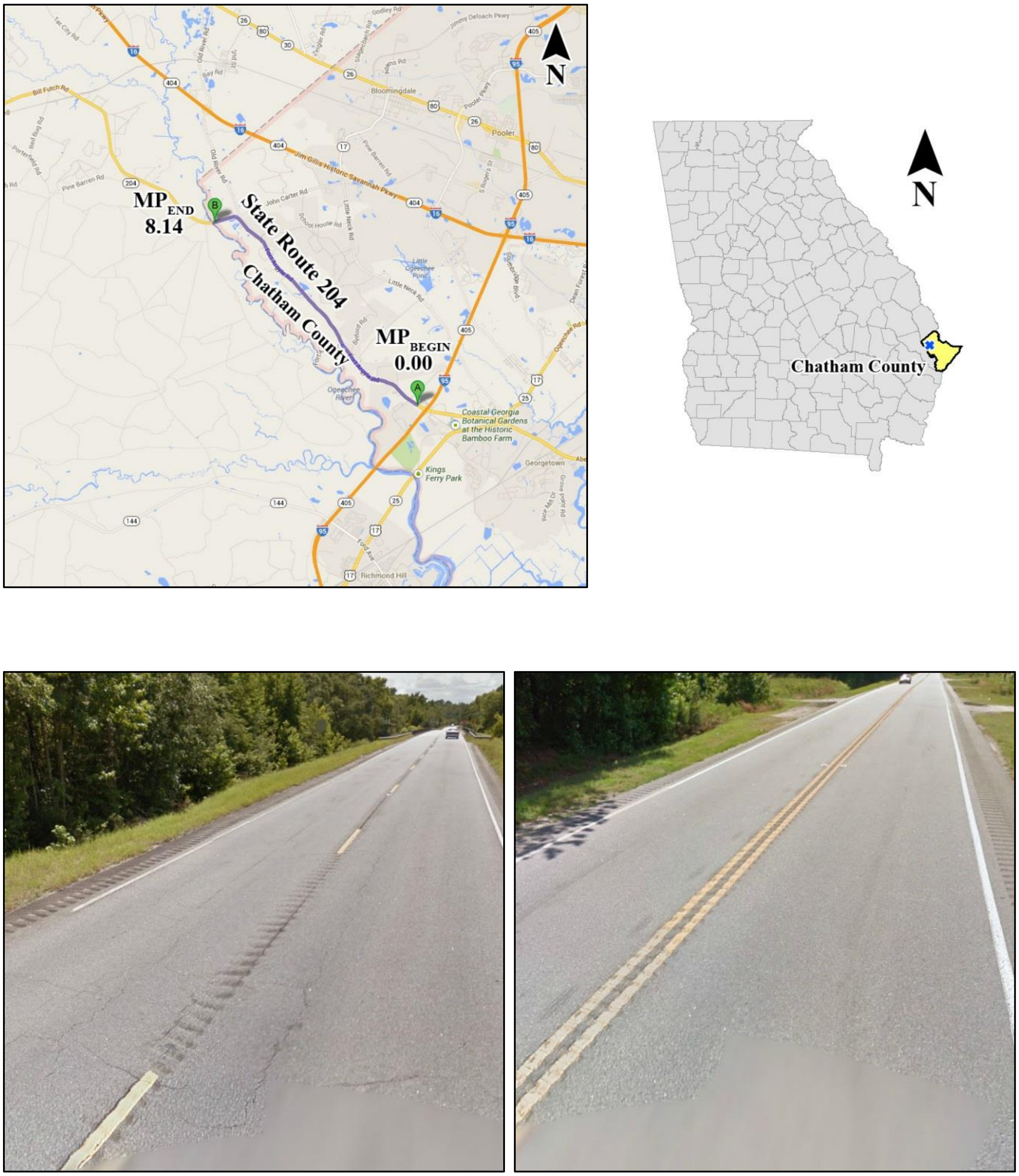


Figure 53: Project 0006976 SR 204 Details (clockwise from top left): Map [14], Location within Georgia, MP 8 Facing West [15], MP 1 Facing East [15]

Table 93: Project 0006976, SR 204, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0006976
	Project Number	CSSTP-0006-00(976)
	Project Title	SR 204 FM BRYAN COUNTY LINE TO I-95-CENTERLINE RUMBLE STRIPS
	Management Let	8/19/2005
	Project Completion	12/3/2009
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	5
	Congressional District	1, 12
	Project Description	This safety improvement project consists of installing centerline ground-in rumble strips on State Route 204 in Chatham County from the Bryan County line to I-95. The intent of this project is to reduce the frequency of head-on and opposite-direction sideswipe crashes.
	Construction Contractor	Peek Pavement Marking, LLC
	MPO	Savannah TMA
Federal Report of Completed Projects	Construction Begin Date	2/14/2006
	Time Charges Stop Date	2/28/2006

Table 94: Project 0006976, SR 204, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 204
Beginning Milepost	0.00
Ending Milepost	8.14
County (Begin)	Chatham
County (End)	Chatham
Length (mi)	8.14
RCLINK	0511020400
Beginning Coordinates	32.079743,-81.383479
Ending Coordinates	32.006607,-81.28781
AADT MP 0.00 – 0.63	2003 – 3,810 2004 – 3,810 2007 – 4,020 2008 – 3,310
AADT MP 0.69 – 8.32	2003 – 7,530 2004 – 7,530 2007 – 7,420 2008 – 6,710

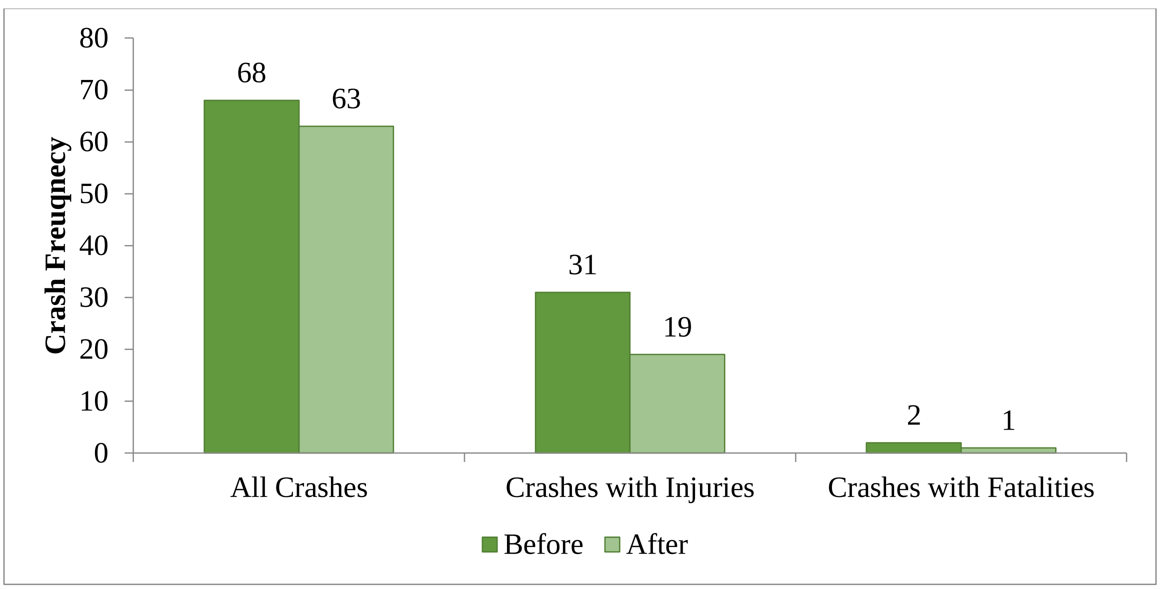


Figure 54: Project 0006976, SR 204, Before and After Crash Frequencies

Project ID: 0007077, SR 36 Section A

Figure 55: Project 0007077 SR 36, Section A Details (clockwise from top left): Map [14], Location within Georgia, MP 0 Facing West [15], MP 10 Facing West [15]

Table 95: Project 0007077, SR 36, Section A, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0007077
	Project Number	CSSTP-0007-00(077)
	Project Title	SR 36 FM SR 74 TO SR 7 & SR 36 FM SR 7 TO I-75
	Management Let	8/19/2005
	Project Completion	12/3/2009
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3
	Congressional District	8
	Project Description	Indentation centerline rumble strips on SR 36 from East Main Street to Peach Blossom Trail
	Construction Contractor	Costello Industries, Incorporated
	MPO	Not Urban
Federal Report of Completed Projects	Construction Begin Date	1/17/2006
	Time Charges Stop Date	5/31/2006

Table 96: Project 0007077, SR 36, Section A, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 36
Beginning Milepost	9.34
Ending Milepost	4.10
County (Begin)	Upson
County (End)	Lamar
Length (mi)	12.03
RCLINK	1711003600 2931003600
Beginning Coordinates	32.920363,-84.28954
Ending Coordinates	33.037692,-84.165099
AADT MP 8.84 – 11.05 (Upson County)	2003 – 6,080 2004 – 6,080 2007 – 7,360 2008 – 7,130
AADT MP 11.06 – 15.71 (Upson County)	2003 – 5,310 2004 – 5,310 2007 – 4,120 2008 – 3,700
AADT MP 15.72 – 19.11 (Upson County)	2003 – 5,030 2004 – 5,030 2007 – 4,910 2008 – 4,720
AADT MP 0.00 – 1.92 (Lamar County)	2003 – 4,400 2004 – 4,400 2007 – 5,670 2008 – 5,010
AADT MP 1.93 – 4.18 (Lamar County)	2003 – 4,800 2004 – 4,800 2007 – 5,280 2008 – 5,080

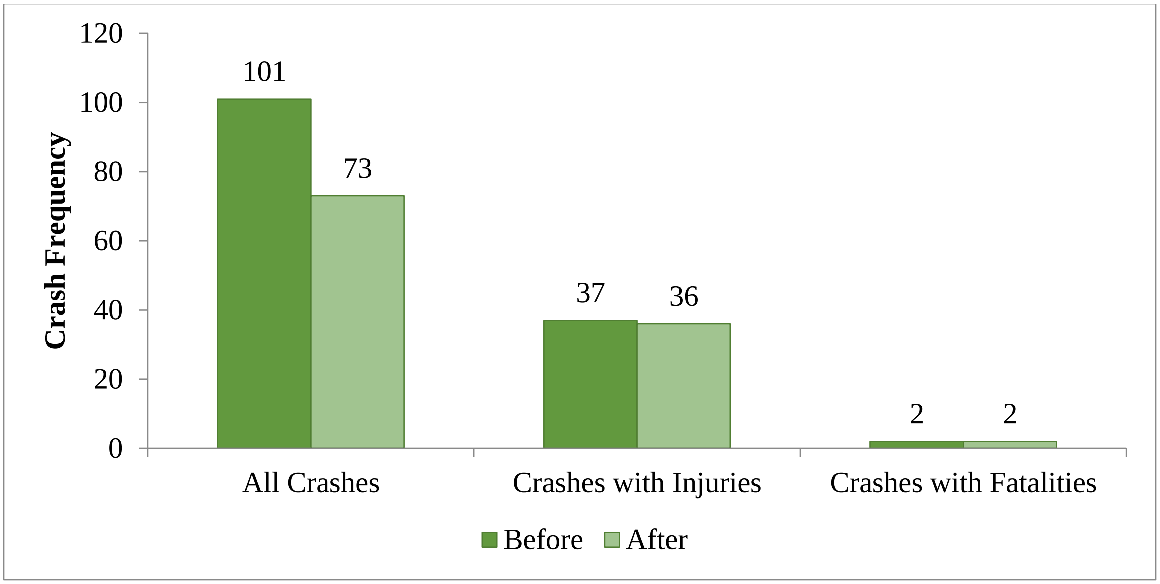
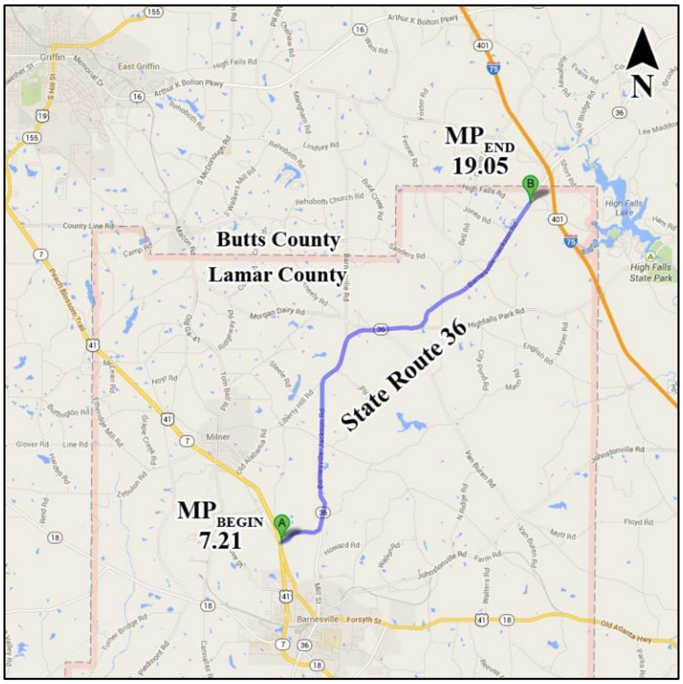


Figure 56: Project 0007077, SR 36, Section A Before and After Crash Frequencies

Project ID: 0007077, SR 36 Section B



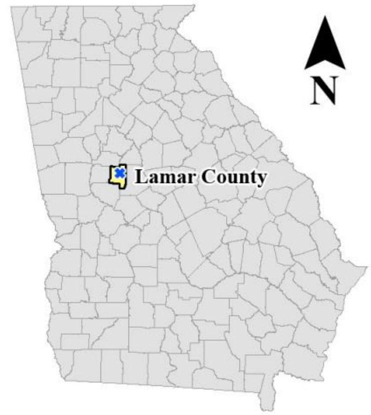


Figure 57: Project 0007077 SR 36, Section B Details (clockwise from top left): Map [14], Location within Georgia, MP 15 Facing West [15], MP 8 Facing West [15]

Table 97: Project 0007077, SR 36, Section B, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0007077
	Project Number	CSSTP-0007-00(077)
	Project Title	SR 36 FM SR 74 TO SR 7 & SR 36 FM SR 7 TO I-75
	Management Let	8/19/2005
	Project Completion	12/3/2009
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	3
	Congressional District	8
	Project Description	SR 36 from Highway 41 to I-75 in District 3
	Construction Contractor	Costello Industries, Incorporated
	MPO	Not Urban
Federal Report of Completed Projects	Construction Begin Date	1/17/2006
	Time Charges Stop Date	5/31/2006

Table 98: Project 0007077, SR 36, Section B, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 36
Beginning Milepost	7.21
Ending Milepost	19.05
County (Begin)	Lamar
County (End)	Lamar
Length (mi)	11.84
RCLINK	1711003600
Beginning Coordinates	33.080741,-84.170817
Ending Coordinates	33.196695,-84.06902
AADT MP 7.17 – 13.5	2003 – 5,990 2004 – 5,990 2007 – 6,280 2008 – 5,870
AADT MP 13.51 – 16.71	2003 – 6,760 2004 – 6,760 2007 – 5,460 2008 – 5,200
AADT MP 16.83 – 18.59	2003 – 5,770 2004 – 5,770 2007 – 7,060 2008 – 6,250
AADT MP 18.60 – 19.28	2003 – 7,120 2004 – 7,120 2007 – 7,640 2008 – 7,270

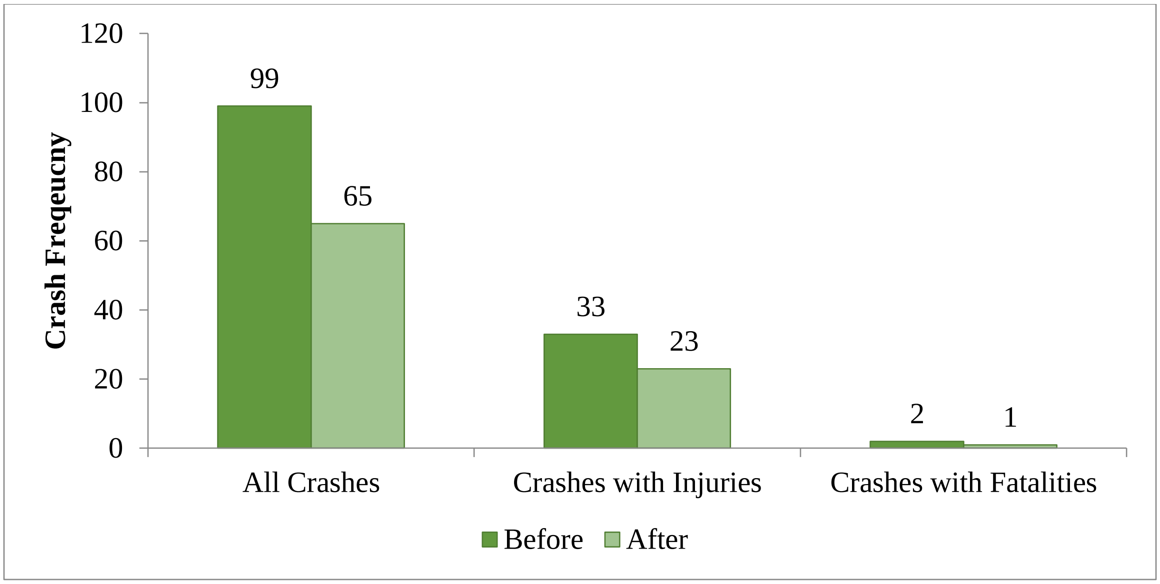
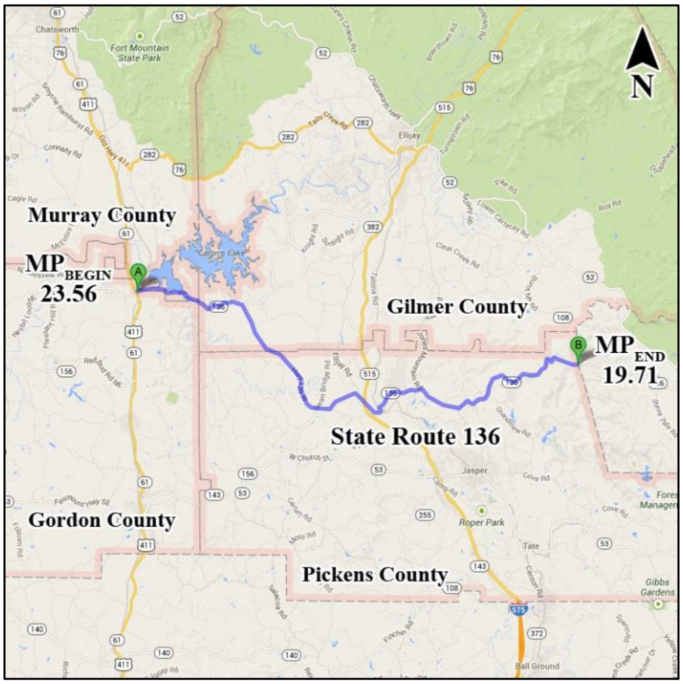


Figure 58: Project 0007077, SR 36, Section B Before and After Crash Frequencies

Project ID: 0007079, SR 136



,

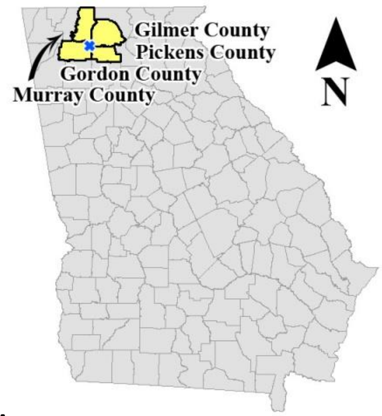


Figure 59: Project 0007079 SR 136 Details (clockwise from top left): Map [14], Location within Georgia, MP 10 (Pickens County) Facing East [15], MP 2 (Murray County) Facing East [15]

Table 99: Project 0007079, SR 136, Construction Details

Source	Attribute	Detail
TransPI	Project ID	0007079
	Project Number	CSSTP-0007-00(079)
	Project Title	SR 136 FROM SR 61/US 411 TO DAWSON COUNTY LINE
	Management Let	8/19/2005
	Project Completion	1/10/2007
	Project Manager	Scott Zehngraff
	Office	Traffic Safety & Design
	Project Type	Safety
	DOT District	6
	Congressional District	9
	Project Description	Indentation centerline rumble strips on SR 136 from SR 61/US 411 to Pickens County line in District 6
	Construction Contractor	-
	MPO	Not Urban
Federal Report of Completed Projects	Construction Begin Date	1/17/2006
	Time Charges Stop Date	5/31/2006

Table 100: Project 0007079, SR 136, Study Details

Attribute	Detail
Primary Roadway	Georgia State Route 136
Beginning Milepost	23.56
Ending Milepost	19.71
County (Begin)	Gordon
County (End)	Pickens
Length (mi)	27.76
RCLINK	1231013600 1291013600 2131013600 2271013600
Beginning Coordinates	34.589751,-84.704502
Ending Coordinates	34.540836,-84.344769
AADT MP 19.99 – 24.07 (Gordon County)	2003 – 2,070 2004 – 2,070 2007 – 1,980 2008 – 1,860
AADT MP 0 – 2.82 (Murray County)	2003 – 2,520 2004 – 2,520 2007 – 2,990 2008 – 2,850
AADT MP 0 – 5.21 (Gilmer County)	2003 – 3,560 2004 – 3,560 2007 – 3,090 2008 – 2,940
AADT MP 0 – 3.66 (Pickens County)	2003 – 2,260 2004 – 2,260 2007 – 2,240 2008 – 2,130
AADT MP 3.67 – 6.31 (Pickens County)	2003 – 3,850 2004 – 3,850 2007 – 4,120 2008 – 3,850
AADT MP 6.32 – 7.24 (Pickens County)	2003 – 1,860 2004 – 1,860 2007 – 1,900 2008 – 1,840

Table 100 Continued on Next Page

Table 100 Continued

Attribute	Detail
AADT MP 7.25 – 12.00 (Pickens County)	2003 – 900 2004 – 900 2007 – 1,260 2008 – 1,100
AADT MP 12.02 – 14.13 (Pickens County)	2003 – 1,970 2004 – 1,970 2007 – 1,820 2008 – 1,730
AADT MP 17.96 – 19.63 (Pickens County)	2003 – 800 2004 – 800 2007 – 630 2008 – 600

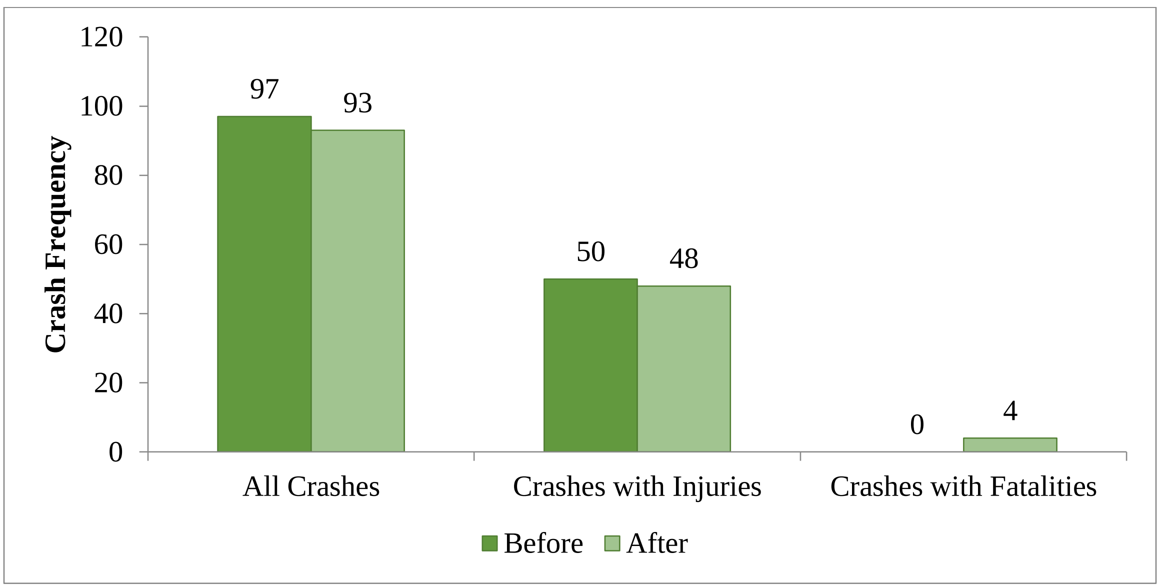


Figure 60: Project 0007079, SR 136 Before and After Crash Frequencies

APPENDIX C

CRASH DATABASE CHARACTERISTICS

C.1 Crash Statistics

The initial annual sanitized crash data files included every crash in Georgia from 2000 to 2009, totaling 3,206,974 crashes. Initially, the time period to be analyzed was three calendar years before and after centerline rumble strips installation. During the course of this study, data constraints were discovered and the analysis time period was cut back to two calendar years before and after the installation. Plotting the number of crashes per month per year of the study roadways reveals that the data of 2009 was incomplete. This is especially evident in the months of October through December, as displayed in Figure 61.

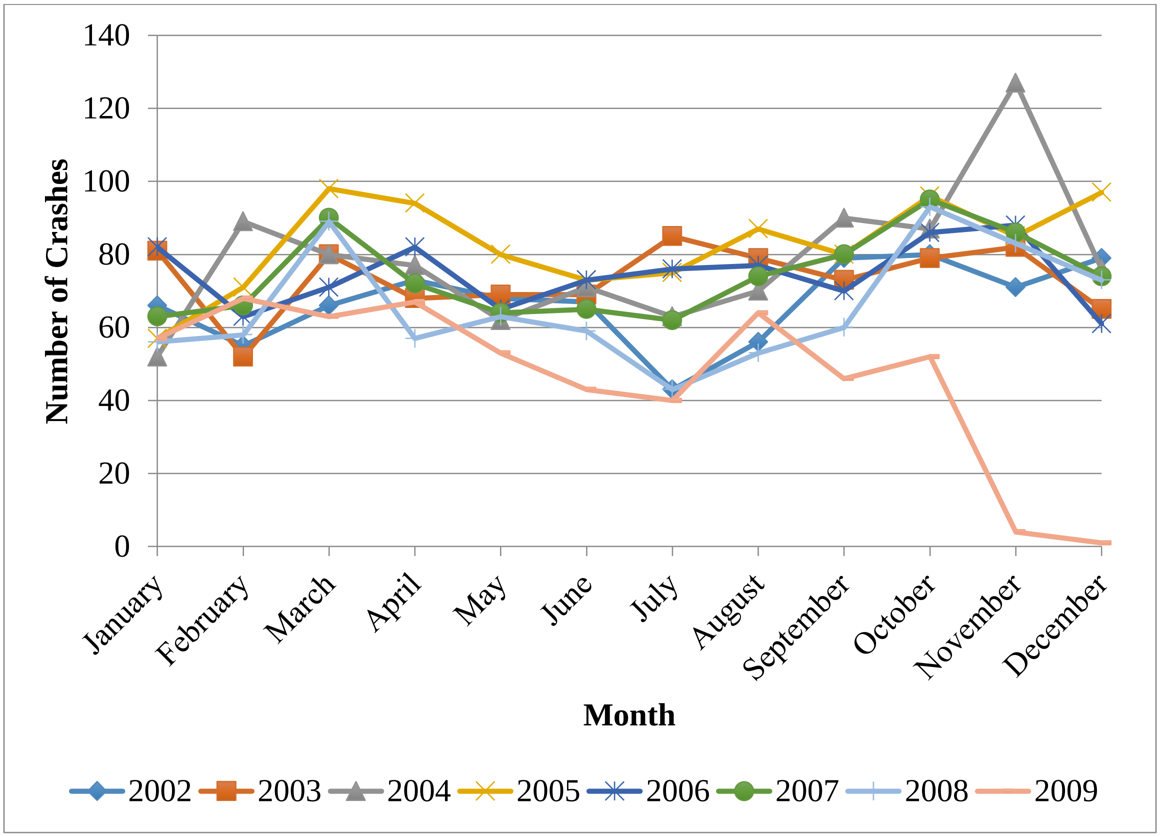


Figure 61: Crashes per Month

Furthermore, this trend was not a localized trend but it existed in the overall crash database as well. Because the crash data included millions of incidents, not every single incident could be verified due to time constraints. Therefore, even after limiting the study period to exclude 2009 crash data, there is an underlying assumption in this study that the crash data for years 2003-2004 and 2007-2008 are accurate.

C.2 Crash Databases

Every crash entry was associated with a breadth of information and was separated into eight tables, each containing different attributes. These tables are, in alphabetical order:

- Accident Table (Table 101)
- Commercial Table

Locations Table (

- Table 102)
- Occupants/Driver Table (Table 103)
- Passengers Table (Table 104)
- Pedestrian Table
- Ramp Table
- Vehicles Table (Table 105)

The following tables list the fields and relevant information within each attributes table that was used in this study. Of the eight tables, only the Accident Table and the Locations Table were used in the analysis. However, information from the Occupants/Driver Table, Passengers Table, and Vehicles Table were also examined in the duration of this study. Though the majority of the fields were not used, these crash attributes contain information that may form the basis of future studies.

Table 101: Accidents Table Attributes

Field Name	Description	Coded Values
ACC_ID	Accident ID	
ACC_ACCNO	Accident Number	
ACC_NCICNO	NCIC Number	
ACC_JULDT	Accident Date	
ACC_CNTY_TYPE	DPS County Code	
ACC_ATIME	Accident Time	
ACC_TNV	Total # of Vehicles	
ACC_TNI	Total # of Injuries	
ACC_TNF	Total # of Fatalities	
ACC_ICO_TYPE	DPS City Code	
ACC_EMSN	Time EMS Notified	
ACC_EMSA	Time EMS Arrived	
ACC_HOSA	Time Arrived at Hospital	
ACC_INVS	Accident Investigation Site	Y/N
ACC_CIT	Citation Issued	Y/N
ACC_HE1_TYPE	First Harmful Event	01-Overturn 02-Fire/Explosion 03-Immersion 04-Jackknife 05-Other Non-Collision 06-Pedestrian 07-Pedalcycle 08-Railway Train 09-Animal 10-Parked Motor Vehicle 11-Motor Vehicle in Motion 12-Motor Vehicle in Motion - In Other Roadway 13-Other Object (Not Fixed) 14-Deer 15-Impact Attenuator 16-Bridge Pier/Abutment 17-Bridge Parapet End

Table 101 Continued on Next Page

Table 101 Continued

Field Name	Description	Coded Values
ACC_HE1_TYPE	First Harmful Event	18-Bridge Rail 19-Guardrail Face 20-Guardrail End 21-Median Barrier 22-Highway Traffic Sign Post 23-Overhead Sign Support 24-Luminaire/Light Support 25-Utility Pole 26-Other Post 27-Culvert 28-Curb 29-Ditch 30-Embankment 31-Fence 32-Mailbox 33-Tree 34-Other Fixed Object
ACC_WEAT_TYPE	Weather	1-Clear 2-Cloudy 3-Rain 4-Snow 5-Sleet 6-Fog 7-Other
ACC_SURF_TYPE	Surface Conditions	1-Dry 2-Wet 3-Snowy 4-Icy 5-Other
ACC_LITE_TYPE	Light Condition	1-Daylight 2-Dusk 3-Dawn 4-Dark-Lighted 5-Dark-Not Lighted

Table 101 Continued on Next Page

Table 101 Continued

Field Name	Description	Coded Values
ACC_MNRC_TYPE	Manner of Collision	1-Angle 2-Head On 3-Rear End 4-Sideswipe - Same Direction 5-Sideswipe - Opposite Direction 6-Not A Collision With A Motor Vehicle
ACC_LOI_TYPE	Location of Impact	1-On Roadway 2-On Shoulder 3-Off Roadway 4-Median 5-Ramp 6-Gore
ACC_RCOMP_TYPE	Road Composition	1-Concrete 2-Black Top 3-Tar and Gravel 4-Dirt 5-Gravel 6-Other
ACC_RDD_TYPE	Road Defects	1-No Defects 2-Defective Shoulders 3-Holes, Deep Ruts, Bumps 4-Loose Material on Surface 5-Water Standing 6-Road Under Construction 7-Running Water 8-Other
ACC_RCHAR_TYPE	Road Characteristics	1-Straight and Level 2-Straight on Grade 3-Straight on Hillcrest 4-Curve and Level 5-Curve on Grade 6-Curve on Hillcrest

Table 101 Continued on Next Page

Table 101 Continued

Field Name	Description	Coded Values
ACC_DAYOFWEEK_TYPE	Day of Week	1-Sunday 2-Monday 3-Tuesday 4-Wednesday 5-Thursday 6-Friday 7-Saturday

Table 102: Location Table Attributes

Field Name	Description	Coded Values
LOC_ACC_ID	Accident ID	
LOC_ACC_JULDT	Accident Date	
LOC_RCLINK_IDENTIFIER	RC Link Number	
LOC_CITY_IDENTIFIER	GDOT City Code	
LOC_COUNTY_IDENTIFIER	GDOT County Code	
LOC_ROUTE_TYPE	Route Type	0-Accident Not Located 1-State Route 2-County Road 3-City Street 8-Public Road 9-Collector-Distributor
LOC_ROUTE_IDENTIFIER	Route Number	
LOC_ROUTE_SUFFIX	Route Suffix	
LOC_ACC_MILELOG	Milelog	
LOC_ACC_MILELOGCUM	Accumulated Milelog	
LOC_INTERROUTE_TYPE	Intersecting Route Type	1-State Route 2-County Road 3-City Street 8-Public Road 9-Collector-Distributor
LOC_INTERROUTE_IDENTIFIER	Intersecting Route Number	
LOC_INTERROUTE_SUFFIX	Intersection Route Suffix	

Table 102 Continued on Next Page

Table 102 Continued

Field Name	Description	Coded Values
LOC_ACCESSCONTROL_TYPE	Access Control	U-Uncontrolled P-Partial Control F-Full Control
LOC_AADT_COUNT	Average Daily Traffic	
LOC_AUXLANELEFT_TYPE	Left Auxiliary Lane Type	A-Left Turn B-Right Turn C-Left Turn and Right Turn D-Left-Lane in Center of Road E-Passing or Climbing Lane F-Parking Lane G-Angle Parking H-Left Turn and Parking I-Left-Left Lane in Center of Road and Parking J-Left-Left Lane in Center of Road and Right Turn K-Marked or Striped Median in Center of Road L-Left Turn and Other M-Striped Median in Center and Other Undivided Roads Only N-Right Turn and Other must be marked with an arrow O-All Additional non-thru roadway not listed P-Parking and Other

Table 102 Continued on Next Page

Table 102 Continued

Field Name	Description	Coded Values
LOC_AUXLANELEFT_TYPE	Left Auxiliary Lane Type	Q-Left-Left Turn and Other R-Left Turn, Right Turn and Other T-Transition Lane
LOC_AUXLANERIGHT_TYPE	Right Auxiliary Lane Type	Same as AUXLANELEFT
LOC_AUXLANELEFT_WIDTH	Left Auxiliary Lane Width	
LOC_AUXLANERIGHT_WIDTH	Right Auxiliary Lane Width	
LOC_DIVHWYBARRIER_TYPE	Divided Highway Barrier Type	0-No Barrier 1-Curb 2-Guardrail 3-Curb and Guardrail 4-Fence 5-New Jersey Concrete Barrier 6-Cable 7-Other
LOC_DIVHWYMEDIAN_TYPE	Divided Highway Median Type	0-Undivided Road 1-Grass 2-Soil, Stone 3-Park, Business 4-Couplet 5-Concrete 6-Other 7-Roadway Separated by Barrier Only

Table 102 Continued on Next Page

Table 102 Continued

Field Name	Description	Coded Values
LOC_FEDELIG_TYPE	Federal Eligibility Designation	1-Interstate 139a-eligible for IM funding 2-Interstate 139a-not eligible for IM funding 3-NHS 4-STP 5-Interstate 139a 6-Interstate 139a 7-Interstate 139b 8-Non-Federal Aid
LOC_FUNCTIONALCLASS_TYPE	Functional Classification	01-Rural-Interstate Principal Arterial 02-Rural-Principal Arterial 06-Rural-Minor Arterial 07-Rural-Major Collector 08-Rural-NFA Minor Collector 09-Rural-Local 11-Urban-Interstate Principal Arterial 12-Urban Freeway and Expressway 14-Urban Principal Arterial 16-Urban-Minor Arterial Street 17-Urban-Collector Street 19-Urban-Local

Table 102 Continued on Next Page

Table 102 Continued

Field Name	Description	Coded Values
LOC_RURALURBAN_TYPE	Rural Urban Road Type	1-Rural Outside Incorporated Area 2-Incorporated Outside Urban Area 3-Rural Inside an Urban Area 4-Incorporated Inside Urban Area 5-Unincorporated Inside Urbanized Area 6-Incorporated Inside and Urbanized Area
LOC_SIGNAL_TYPE	Road Signal Type	S-Traffic Control Device (Red,Amber,Green P-Traffic Control w/Pedestrian Signalization A-Stop Sign F-Flasher-Other than Overhead Beacon L-Traffic Control Device with Turn Arrow B-Beacon-Overhead Flashing Amber R-Beacon-Overhead Flashing Red C-Stop All Direction Y-Yield Sign W-Yield Sign Opposite Direction of Inventory O-Stop Sign Opposite Direction of Inventory
LOC_SPEEDLIMIT_NUMBER	Speed Limit	
LOC_LANESLEFT_COUNT	Number of Left Lanes	
LOC_LANESRIGHT_COUNT	Number of Right Lanes	
LOC_LOCATE_DATE	Accident Located Date	
LOC_LOCATOR_IDENTIFIER	Accident Locator ID	

Table 103: Occupants / Driver Table

Field Name	Description	Coded Values
OCC_ACC_ID	Accident ID	
OCC_VEHNO	Vehicle Number	
OCC_ACC_JULDT	Accident Date	
OCC_DOB	Driver Date of Birth	
OCC_AGE	Driver Age	
OCC_LNST	Driver License State	
OCC_SEX_TYPE	Driver Sex	M-Male F-Female
OCC_ALTST_TYPE	Driver Alcohol Test	1-Yes 2-No 3-Refused 4-Pending 5-See Remarks
OCC_ALTYP_TYPE	Driver Alcohol Test Type	1-Blood 2-Breath 3-Urine 4-Other
OCC_ALRSLT	Driver Alcohol Test Results	
OCC_DRTST_TYPE	Driver Drug Test	1-Yes 2-No 3-Refused 4-Pending 5-See Remarks
OCC_DRGTYP_TYPE	Driver Drug Test Type	1-Blood 2-Breath 3-Urine 4-Other
OCC_DRRSLT	Driver Drug Test Result	

Table 103 Continued on Next Page

Table 103 Continued

Field Name	Description	Coded Values
OCC_DRVCND_TYPE	Driver Condition	1-Not Drinking 2-Not Known if U.I 3-Drinking, Not Impaired 4-U.I. Alcohol 5-U.I. Drugs 6-U.I. Alcohol and Drugs 7-Physical Impairment 8-Apparently Fell Asleep
OCC_INJC_TYPE	Driver Injury Type	0-Not Injured 1-Killed 2-Serious 3-Visible 4-Compliant
OCC_TREA	Driver Treatment	Y/N
OCC_EJECT_TYPE	Driver Ejection Type	1-Not Ejected 2-Trapped 3-Totally Ejected 4-Partially Ejected
OCC_SAFE_TYPE	Driver Safety Equipment Type	0-None Used 1-Shoulder Belt 2-Lap Belt 3-Lap and Shoulder Belt 4-Child Safety Seat (Properly Used 5-Child Safety Seat (Improperly Used 6-Motorcycle Helmet 7-Bicycle Helmet 8-Unknown
OCC_EXTR	Driver Extrication	Y/N
OCC_AIRB_TYPE	Driver Airbag Type	0-No Airbag in Vehicle 1-Deployed Airbag 2-Non-Deployed Airbag

Table 104: Passenger Table Attributes

Field Name	Description	Coded Values
OCC_ACC_ID	Accident ID	
OCC_VEHNO	Vehicle Number	
OCC_NO	Passenger Number	
OCC_ACC_JULDT	Accident Date	
OCC_AGE	Passenger Age	
OCC_SEX_TYPE	Passenger Sex	M-Male F-Female
OCC_POS_TYPE	Passenger Position	2-Middle Front Seat 3-Window Front Seat 4-Driver Side Window Rear Seat 5-Middle Rear Seat 6-Passenger Side Window Rear Seat 7-Trunk 8-Outside the Vehicle
OCC_INJC_TYPE	Passenger Injury	0-Not Injured 1-Killed 2-Serious 3-Visible 4-Compliant
OCC_TREA	Passenger Treatment	Y/N
OCC_EJEC_TYPE	Passenger Ejection	1-Not Ejected 2-Trapped 3-Totally Ejected 4-Partially Ejected

Table 104 Continued on Next Page

Table 104 Continued

Field Name	Description	Coded Values
OCC_SAFE_TYPE	Passenger Safety Equipment	0-None Used 1-Shoulder Belt 2-Lap Belt 3-Lap and Shoulder Belt 4-Child Safety Seat (Properly Used 5-Child Safety Seat (Improperly Used 6-Motorcycle Helmet 7-Bicycle Helmet 8-Unknown
OCC_EXTR	Passenger Extrication	Y/N
OCC_AIRB_TYPE	Passenger Airbag	0-No Airbag in Vehicle 1-Deployed Airbag 2-Non-Deployed Airbag

Table 105: Vehicles Table Attributes

Field Name	Description	Coded Values
VEH_ACC_ID	Accident ID	
VEH_NO	Vehicle Number	
VEH_ACC_JULDT	Accident Date	
VEH_TAGST	Vehicle Tag State	
VEH_DIRT_TYPE	Vehicle Direction of Travel	1-North 2-South 3-East 4-West
VEH_VOBS_TYPE	Vision Obscured	1-Not Obscured 2-Headlights 3-Sunlight 4-Parked Vehicle 5-Trees, Bushes 6-Rain, Snow, Ice on Windshield 7-Other

Table 105 Continued on Next Page

Table 105 Continued

Field Name	Description	Coded Values
VEH_CONF1_TYPE	Contributing Factor 1	01-No Contributing Factors 02-D.U.I 03-Following too Close 04-Failed to Yield 05-Exceeding Speed Limit 06-Disregard Stop Sign/Signal 07-Wrong Side of Road 08-Weather Conditions 09-Improper Passing 10-Driver Lost Control 11-Changed Lanes Improperly 12-Object or Animal 13-Improper Turn 14-Parked Improperly 15-Mechanical or Vehicle Failure 16-Surface Defects 17-Misjudged Clearance 18-Improper Backing 19-No Signal/Improper Signal 20-Driver Condition 21-Driverless Vehicle 22-Too Fast for Conditions 23-Improper Passing of School Bus 24-Disregard Police Officer 25-Distracted 26-Other
VEH_CONF2_TYPE	Contributing Factor 2	Default to spaces if not entered. Otherwise use the same rules as Contributing Factor 1

Table 105 Continued on Next Page

Table 105 Continued

Field Name	Description	Coded Values
VEH_CONF3_TYPE	Contributing Factor 3	Default to spaces if not entered. Otherwise use the same rules as Contributing Factor 1
VEH_CONF4_TYPE	Contributing Factor 4	Default to spaces if not entered. Otherwise use the same rules as Contributing Factor 1
VEH_COND_TYPE	Vehicle Condition	1-No Known Defects 2-Tire Failure 3-Brake Failure 4-Improper Lights 5-Steering Failure 6-Slick Tires 7-Other
VEH_MANV_TYPE	Vehicle Maneuver	01-Turning Left 02-Turning Right 03-Making U-Turn 04-Stopped 05-Straight 06-Changing Lanes 07-Backing 08-Parked 09-Passing 10-Negotiating a Curve 11-Entering/Leaving Parking 12-Entering/Leaving Driveway
VEH_MHE_TYPE	Most Harmful Event	01-Overturn 02-Fire/Explosion 03-Immersion 04-Jackknife 05-Other Non-Collision 06-Pedestrian 07-Pedalcycle 08-Railway Train

Table 105 Continued on Next Page

Table 105 Continued

Field Name	Description	Coded Values
VEH_MHE_TYPE	Most Harmful Event	09-Animal 10-Parked Motor Vehicle 11-Motor Vehicle in Motion 12-Motor Vehicle in Motion - In Other Roadway 13-Other Object (Not Fixed) 14-Deer 15-Impact Attenuator 16-Bridge Pier/Abutment 17-Bridge Parapet End 18-Bridge Rail 19-Guardrail Face 20-Guardrail End 21-Median Barrier 22-Highway Traffic Sign Post 23-Overhead Sign Support 24-Luminaire/Light Support 25-Utility Pole 26-Other Post 27-Culvert 28-Curb 29-Ditch 30-Embankment 31-Fence 32-Mailbox 33-Tree 34-Other Fixed Object
VEH_CLASS_TYPE	Vehicle Class	0-Unknown 1-Privately Owned 2-Police 3-Fire 4-School

Table 105 Continued on Next Page

Table 105 Continued

Field Name	Description	Coded Values
VEH_CLASS_TYPE	Vehicle Class	5-Other Government Owned 6-Military 7-Commercial Vehicle 8-Other 9-Commercial Vehicle (No Carrier ID Available)
VEH_TYPE_TYPE	Vehicle Type	01-Passenger Car 02-Pickup Truck 03-Truck Tractor (Bobtail) 04-Tractor/Trailer 05-Tractor W/Twin Trailers 06-Logging Truck 07-Logging Tractor/Trailer 08-Single Unit Truck 09-Panel Truck 10-Van 11-Utility Passenger Vehicle 12-Vehicle With Trailer 13-Bus 14-Truck Towing House Trailer 15-Ambulance 16-Motorized Recreational Vehicle 17-Motorcycle, Scooter, Minibike 18-Moped 19-Pedalcycle, Bicycle 20-Farm or Construction Equipment 21-All Terrain Vehicle 22-Other

Table 105 Continued on Next Page

Table 105 Continued

Field Name	Description	Coded Values
VEH_TRCNTL_TYPE	Traffic Control	1-No Stop Present 2-Traffic Signal 3-RR Signal/Sign 4-Warning Sign 5-Stop or Yield Sign 6-No Passing Zone 7-Lanes 8-Other
VEH_NOCC	Number of Occupants	
VEH_PIC_TYPE	Point of Initial Contact	00-Overturned 01-Passenger Front Fender 02-Passenger Front Door 03-Passenger Middle 04-Passenger Rear Door 05-Passenger Rear Fender 06-Rear End 07-Driver Rear Fender 08-Driver Rear Door 09-Driver Middle 10-Driver Front Door 11-Driver Front Fender 12-Front End 13-Top 14-Undercarriage 15-Non Contact Vehicle
VEH_DAMG_TYPE	Vehicle Damage	0-Pedestrian 1-None 2-Slight 3-Moderate 4-Extensive 5-Fire Present 9-Unknown

APPENDIX D

COMPARATIVE ANALYSIS AADT BIN RESULTS

As mentioned in Chapter 5.4, AADT bins of 500 and 1,000 vpd were analyzed. The results of the other two AADT bins examined in this study are presented in Chapter 5.4.1 and 5.4.2.

D.1 AADT Bins of 500

The following figures show the results from utilizing AADT bins of 500 vpd.

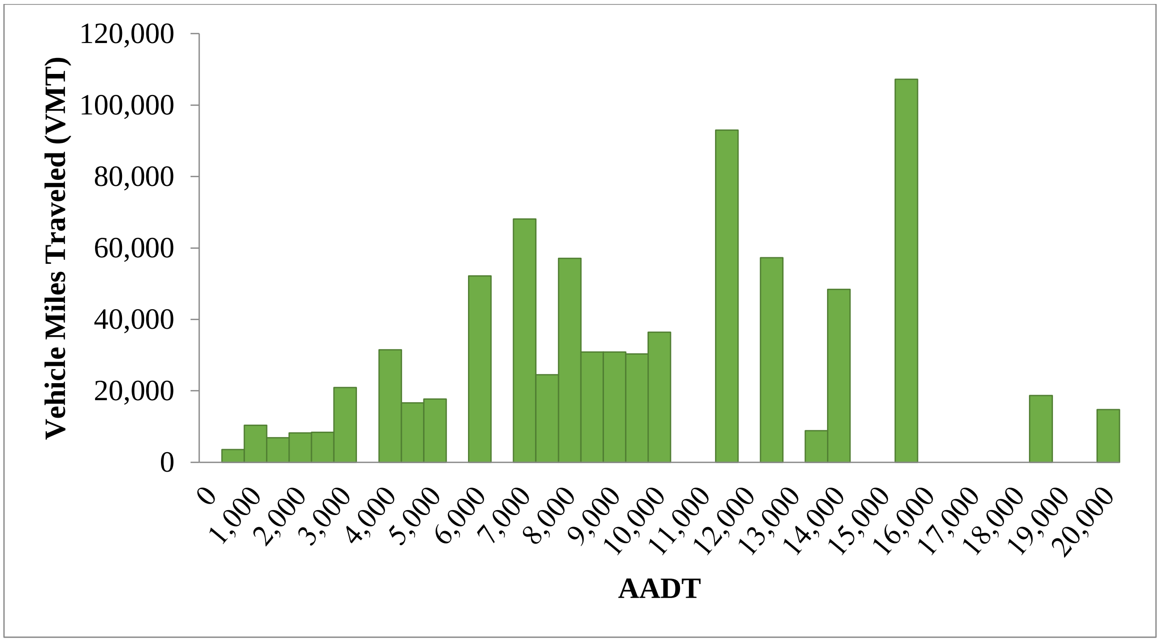


Figure 62: VMT Distribution of Treatment Roadways with AADT Bins of 500

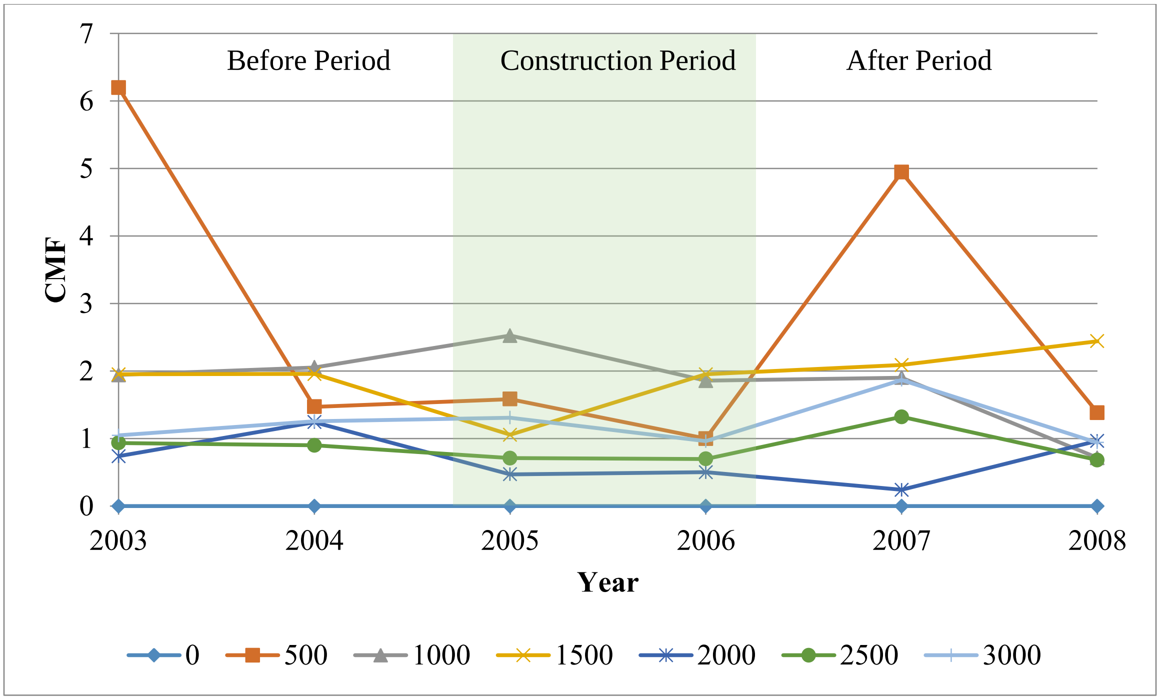


Figure 63: Bins of 500 – CMFs of Roadway Segments with AADTs of 0 to 3499 vpd

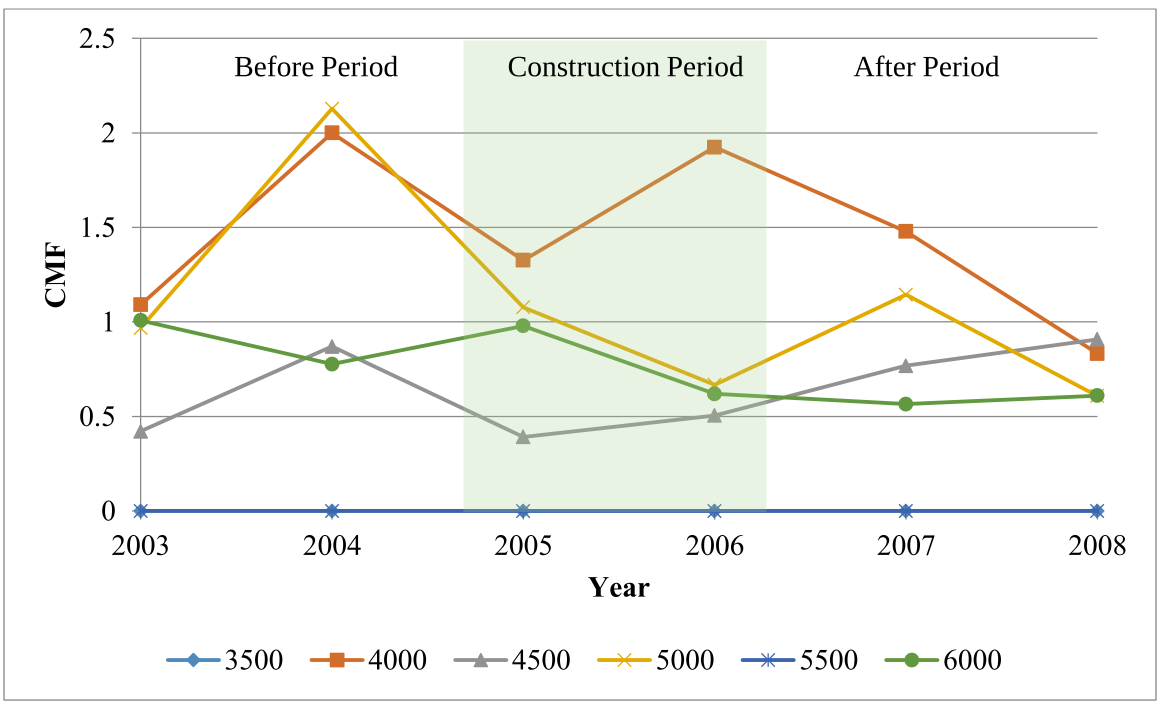


Figure 64: Bins of 500 – CMFs of Roadway Segments with AADTs of 3500 to 6499 vpd

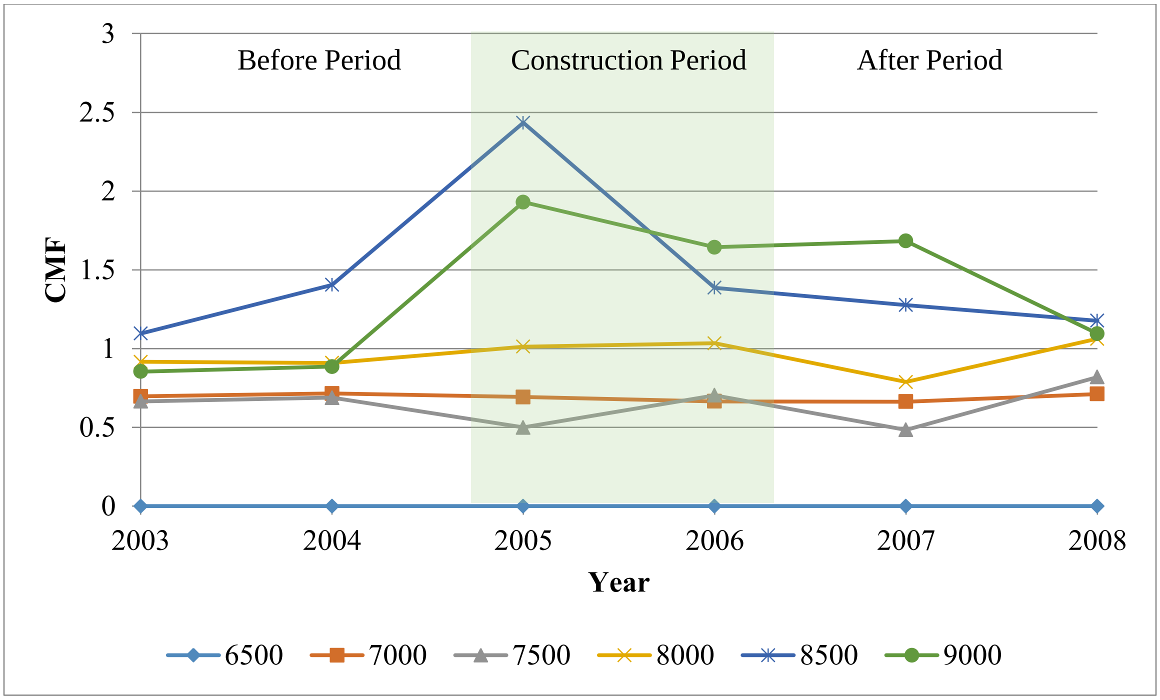


Figure 65: Bins of 500 – CMFs of Roadway Segments with AADTs of 6500 to 9499 vpd

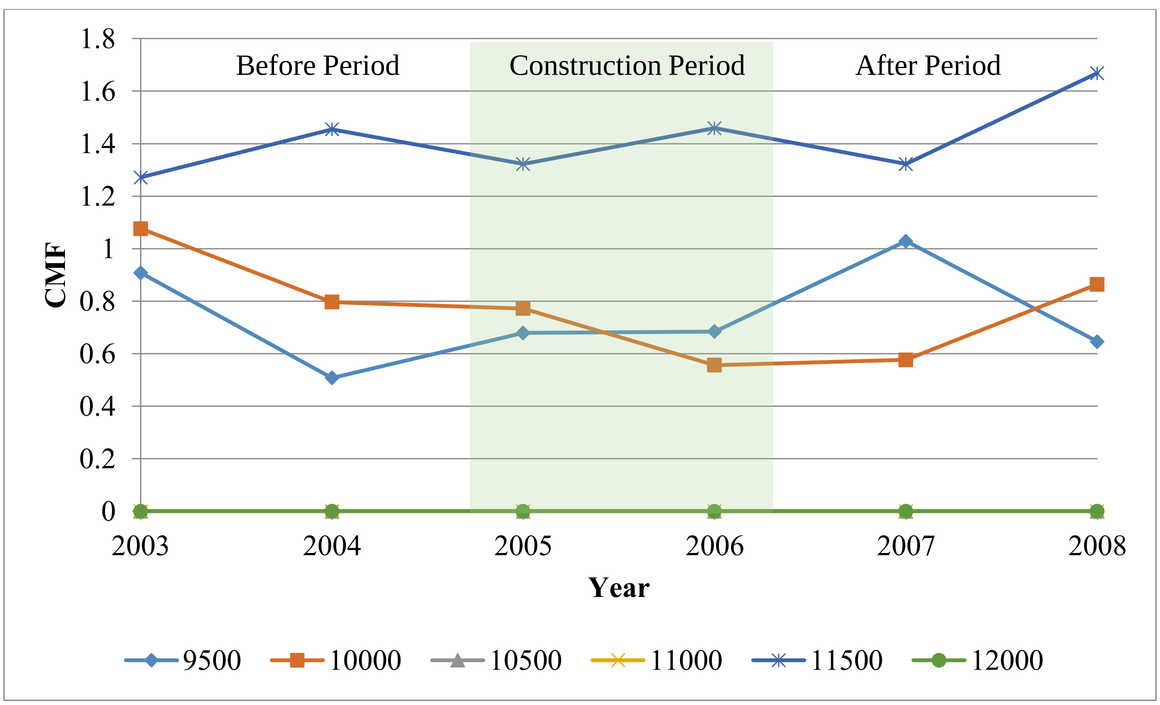


Figure 66: Bins of 500 – CMFs of Roadway Segments with AADTs of 9500 to 12499 vpd

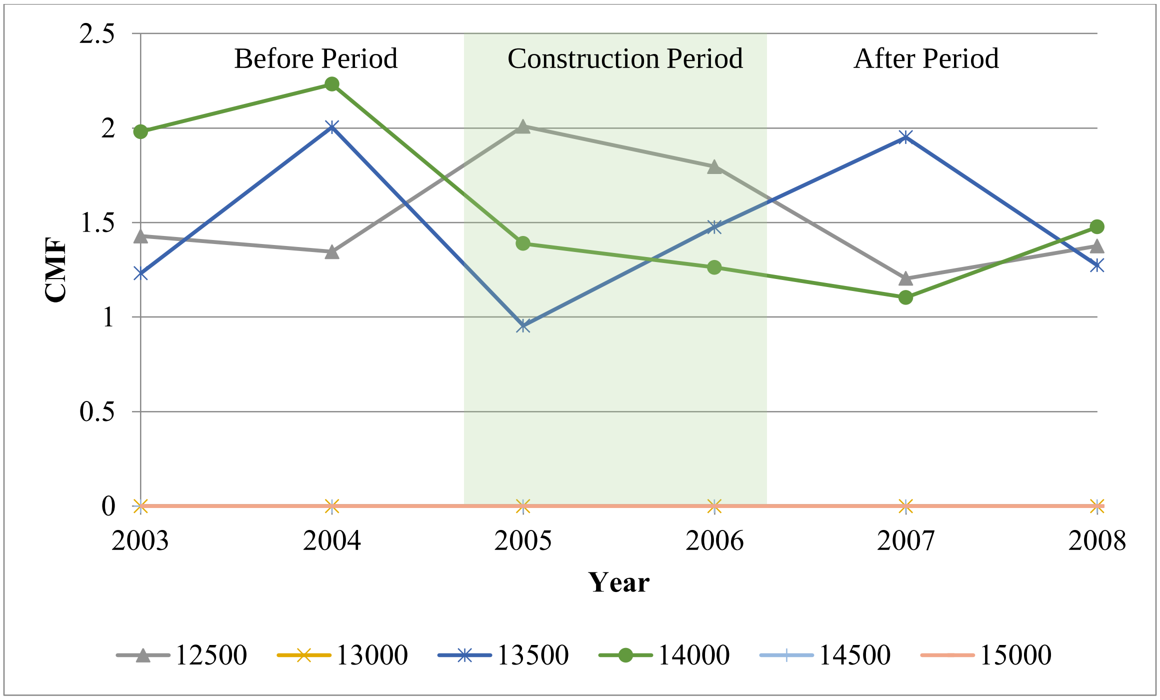


Figure 67: Bins of 500 – CMFs of Roadway Segments with AADTs of 12500 to 15499 vpd

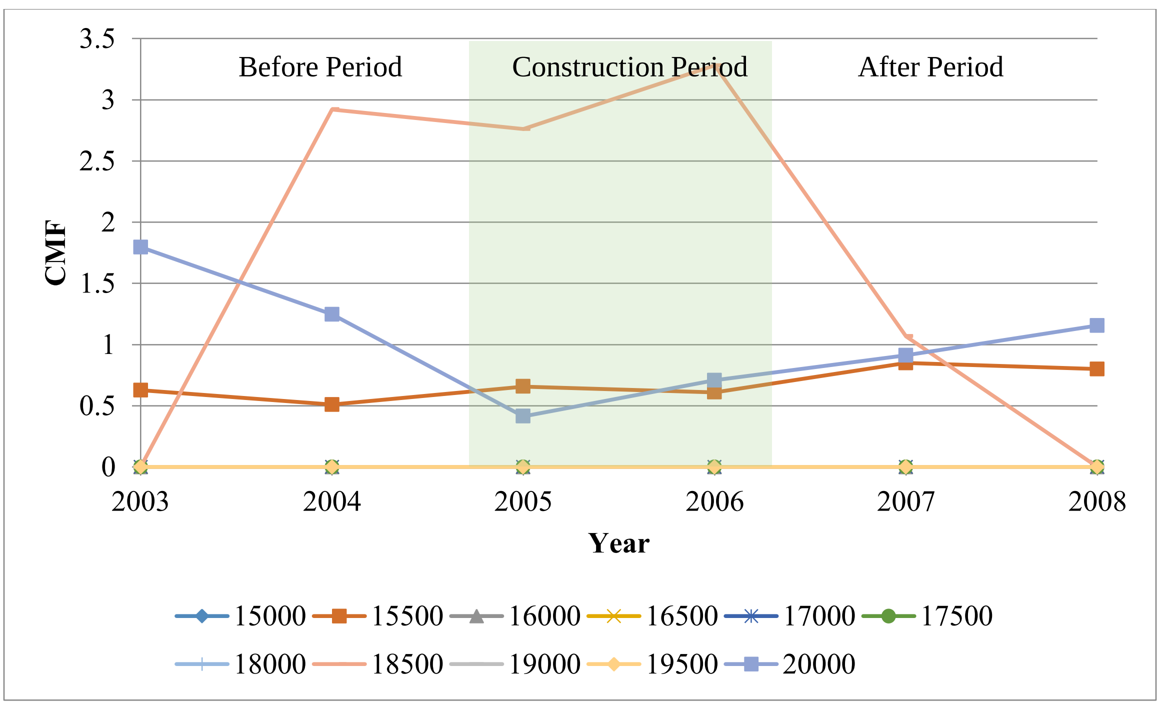


Figure 68: Bins of 500 – CMFs of Roadway Segments with AADTs of 16000 to 20000+ vpd

D.2 AADT Bins of 1,000

The following figures show the results from utilizing AADT bins of 1,000 vpd.

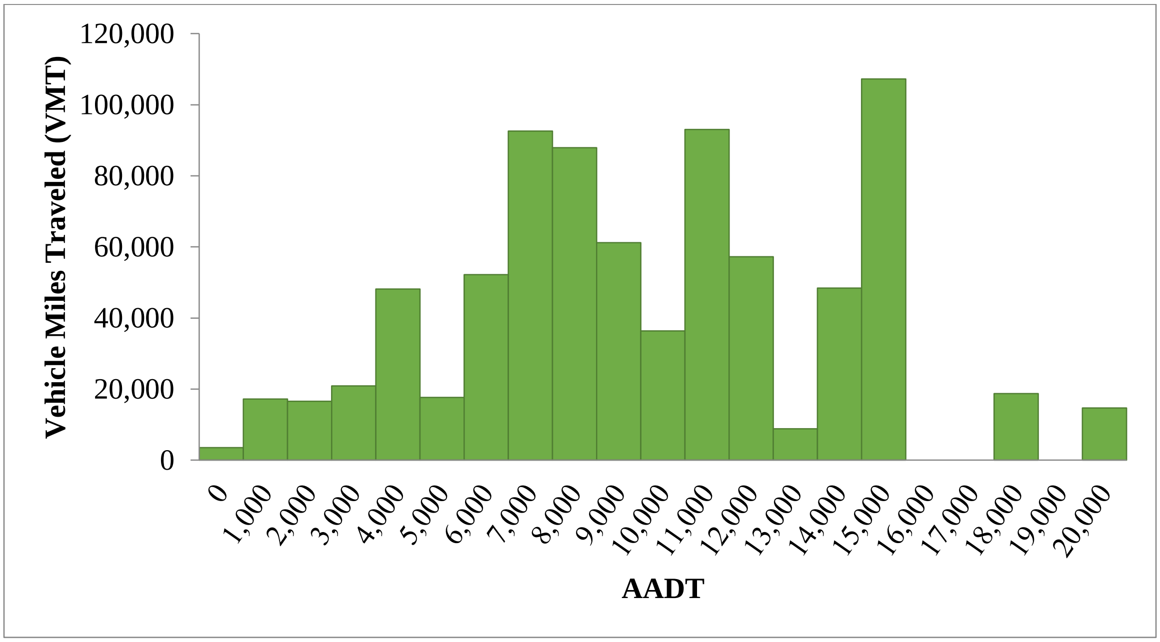


Figure 69: VMT Distribution of Treatment Roadways with AADT Bins of 1,000

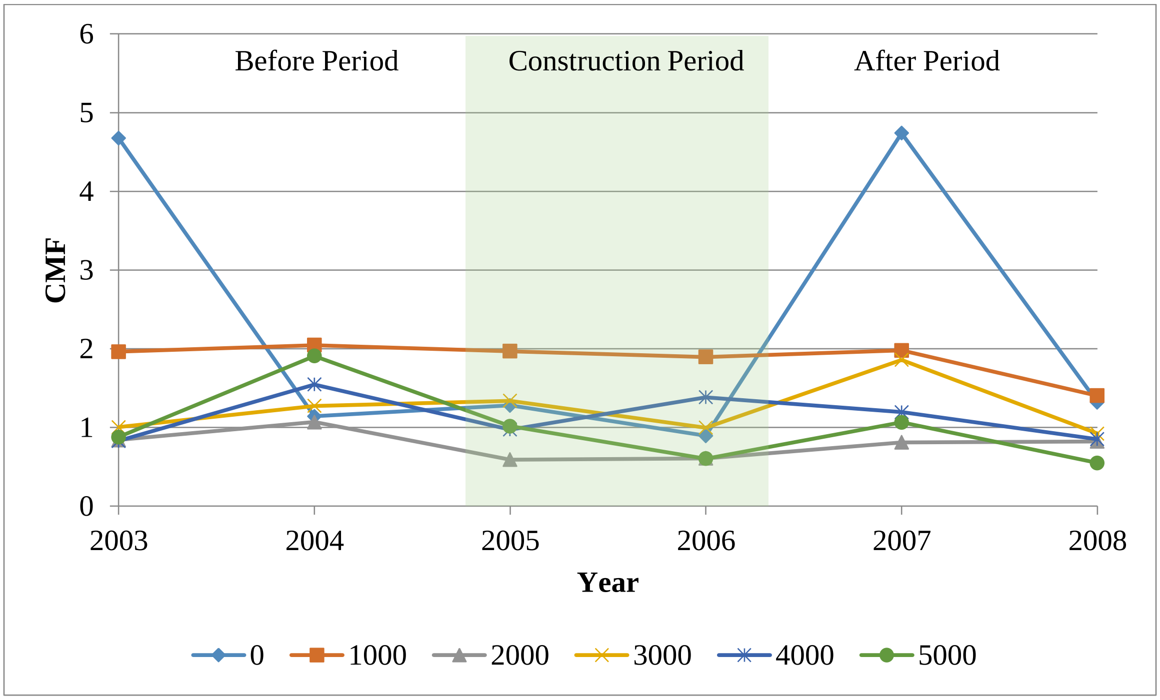


Figure 70: Bins of 1,000 – CMFs of Roadway Segments with AADTs of 0 to 5999 vpd

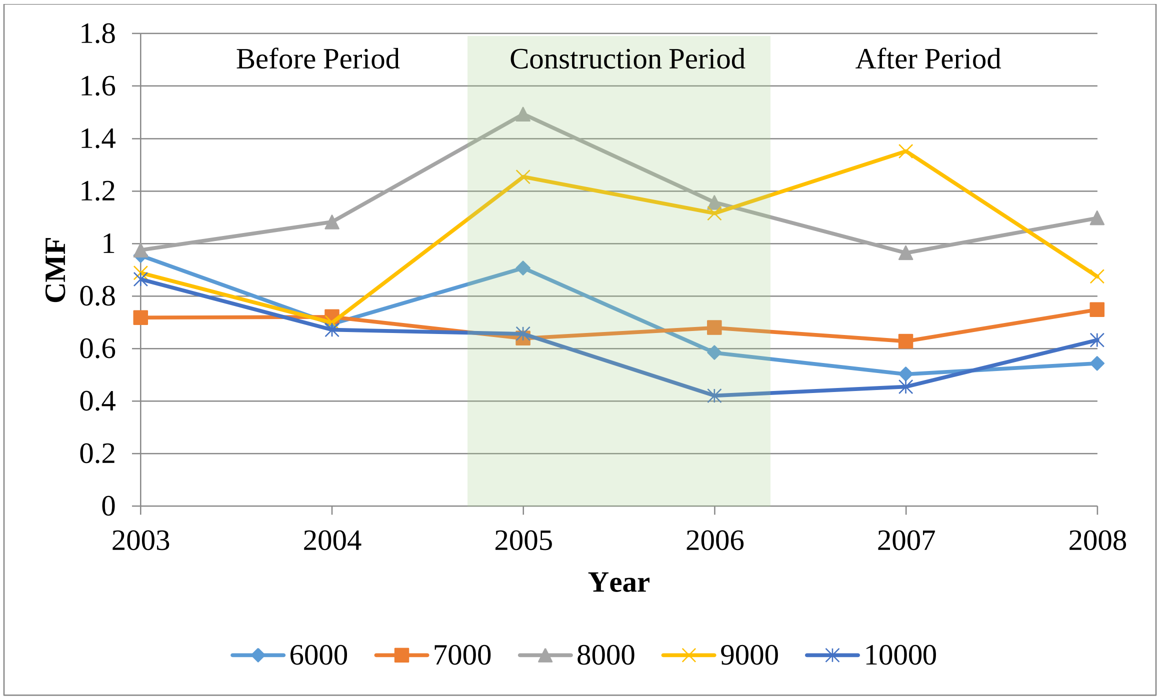


Figure 71: Bins of 1,000 – CMFs of Roadway Segments with AADTs of 6000 to 10999 vpd

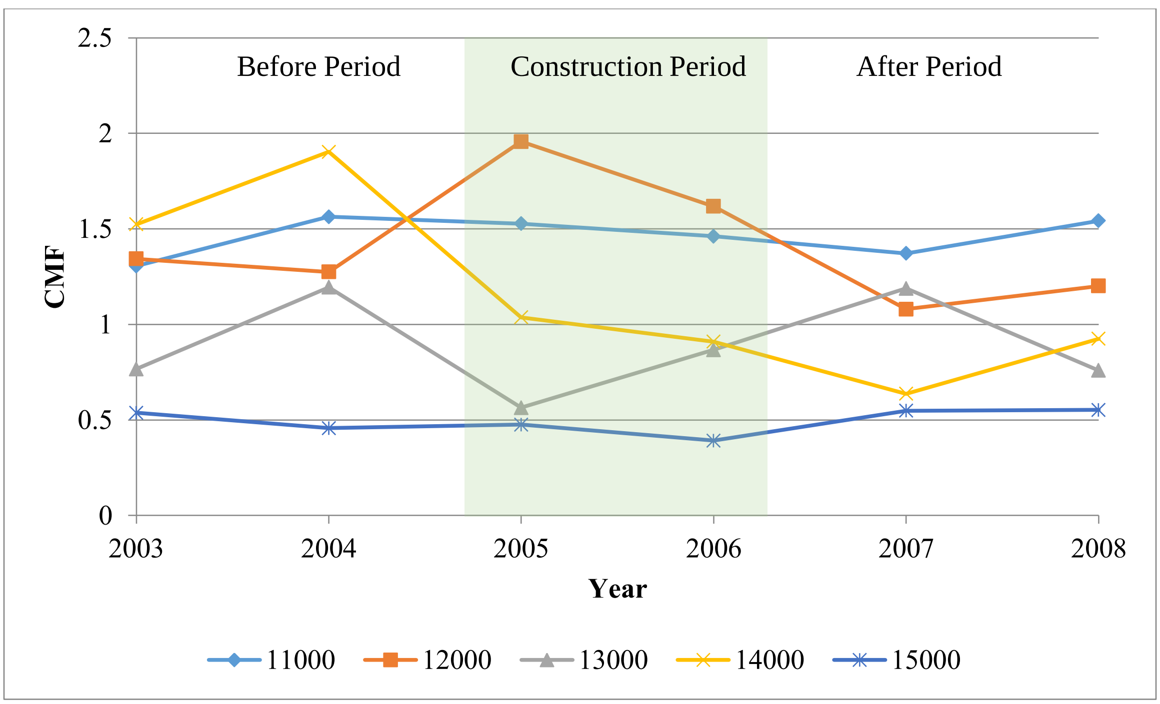


Figure 72: Bins of 1,000 – CMFs of Roadway Segments with AADTs of 11000 to 15999 vpd

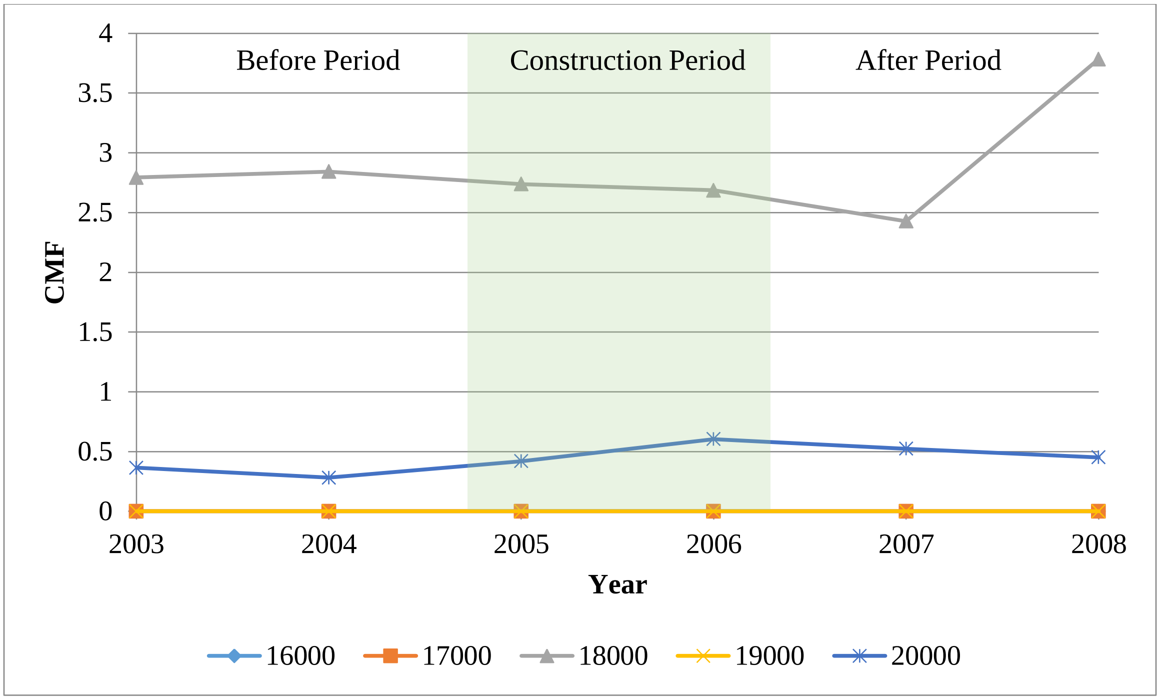


Figure 73: Bins of 1,000 – CMFs of Roadway Segments with AADTs of 16000 to 20000+ vpd

APPENDIX E

SQL AND PERL CODES

Chapter E.1 highlights various SQL codes used to extract data from the crash database in Microsoft Access. Chapter E.2 section highlights a Perl scripts that joined the crash databases with the roadway databases. The Perl scripts were then used for the comparison before-after analysis and the empirical Bayes analysis.

E.1 SQL Codes

Treatment Sites: Before Period

```
SELECT *
FROM LOCATION_TBL
WHERE ((((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0771001400") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
19.68 And 27.55) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0451001600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
16.69 And 27.87) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0771001600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 7.06) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0771015400") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.11 And 7.60) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1171036900") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 19.89) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0351004200") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 7.97) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
```

```
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1511004200") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
4.58 And 9.81) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0511020400") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 8.14) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"2931003600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
9.34 And 19.11) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1711003600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 4.10) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1711003600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
7.21 and 19.05) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1291013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
23.56 And 24.00) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"2131013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 2.79) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1231013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 5.15) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"2271013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 19.71) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2003# and #12/31/2004#)));
```

Treatment Sites: After Period

```
SELECT *
FROM LOCATION_TBL
```

```
WHERE ((((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0771001400") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
19.68 And 27.55) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0451001600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
16.69 And 27.87) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0771001600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 7.06) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0771015400") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.11 And 7.60) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1171036900") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 19.89) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0351004200") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 7.97) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1511004200") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
4.58 And 9.81) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"0511020400") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 8.14) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"2931003600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
9.34 And 19.11) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1711003600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 4.10) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
```

```
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1711003600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
7.21 and 19.05) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1291013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
23.56 And 24.00) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"2131013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 2.79) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"1231013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 5.15) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#))
OR (((LOCATION_TBL.LOC_RCLINK_IDENTIFIER) Like
"2271013600") AND ((LOCATION_TBL.LOC_ACC_MILELOG) Between
0.00 And 19.71) AND ((LOCATION_TBL.LOC_ACC_JULDT) Between
#1/1/2007# and #12/31/2008#)));
```

E.2 Perl Codes

This code was used to join the crash database to the roadway database and was written by Dr. Angshuman Guin.

Joining Treatment Sites to Treatment Roadways

```
use strict;

my $int_filter = 'non_int';
$int_filter = 'int';

my $road_types = 'all';

#LOC_ACC_ID,LOC_ACC_JULDT,LOC_RCLINK_IDENTIFIER,LOC_ACC_MIL
ELOG,LOC_INTERROUTE_TY
#PE,LOC_AADT_COUNT,LOC_DIVHWYBARRIER_TYPE,LOC_DIVHWYMEDIAN_
TYPE,LOC_FUNCTIONALCLA
#SS_TYPE,LOC_LANESLEFT_COUNT,LOC_LANESRIGHT_COUNT,No of
Injured,No of Fatalities,
#Manner of Collision
```

```
my $header =
'COUNTY,ROUTE_TYPE,ROUTE_NUM,BEG_MEASURE,END_MEASURE,SECTIO
N_LENGTH,DESCRIPTION,DISTRICT,MAINT_AREA,POPULATION,INVENTO
RY_DATE,DESIGNATED_WAY,TRUCK_ROUTE,TRAVEL_WAY,RURAL_URAN,SP
EED_LIMIT,FAS_NUM,TRUCK_ROUTE_ID,CONGRESS_DIST,STATE_ROUTE_
SEQ,ACCESS_CONTROL,OPERATION,TOTAL_LANES,SPECIAL_CLASS,DIV_
HWY_SHLDR_WIDTH_LFT,DIV_HWY_SHLDR_TYPE_LFT,DIV_HWY_SURF_WID
TH,DIV_HWY_SURF_TYPE,DIV_HWY_SHLDR_WIDTH_RT,DIV_HWY_SHLDR_T
YPE_RT,DIV_HWY_MEDIAN_WIDTH,DIV_HWY_MEDIAN_TYPE,DIV_HWY_BAR
RIER_TYPE,UDIV_HWY_SHLDR_WIDTH_LFT,UDIV_HWY_SHLDR_TYPE_LFT,
UDIV_HWY_SURFACE_WIDTH,UDIV_HWY_SURFACE_TYPE,UDIV_HWY_SHLDR
_WIDTH_RT,UDIV_HWY_SHLDR_TYPE_RT,AUX_LANE_WIDTH_LFT,AUX_LAN
E_TYPE_LFT,AUX_LANE_WIDTH_RT,AUX_LANE_TYPE_RT,MAINT_YEAR,MA
INT_TYPE,IMPROVE_YEAR,FUNC_CLASS,TRAFFIC_COUNT_TYPE,TRAFFIC
_COUNT_YEAR,RIGHT_OF_WAY,RW_TYPE,TC_NUMBER,MAINTENANCE_SUR_
DES,SIDEWALK_LEFT,SIDEWALK_RIGHT,IMPROVE_TYPE,TRUCK_PERCENT
,TRUCK_PERCENT_TYPE,SIGNAL,AADT_OLD,HPMS_ID,PACES_RATING,AA
DT,INTERSECT_ROAD1,INTERSECT_ROAD2,S_FUNCLASS_ID,DUAL_MAINT
_RATING,ROAD_WIDTH,DIVIDED,OPEN_TO_TRAFFIC,CITY_CODE,T_LANE
S_LEFT,T_LANES_RIGHT,LAND_DOMAIN,RCLINK,Total Crashes,
Injury Crashes, Fatal Crashes,Injury with Fatality,Injury
without Fatality,Fatality without Injury, No Fatality or
Injury,Headon,Sideswipe (opposite dir),Angle,Property Only
';

my $filterf = 'CLRS_Site_Extents.csv';
open FIL, "<$filterf";

my $i = 0;
my @filters;
my $rc_string = ',';
while(<FIL>){
     chomp;
     next unless /^\d/;
     my ($RCLINK,$BEG_MEASURE,$END_MEASURE) = split /,/;
      ($filters[$i][0], $filters[$i][1], $filters[$i][2]) =
($RCLINK,$BEG_MEASURE,$END_MEASURE);
     print "($filters[$i][0], $filters[$i][1],
$filters[$i][2])\n";
     $i++;
```

```
     $rc_string .= "$RCLINK,";
}
my $filter_size = $i-1;
#

my $baselinef = "2012_BaseLine_Road_Data";
$baselinef = "RC_Data_2007";
my @files = glob ("2*Crash*.txt");

open(BASE, "<$baselinef.txt");

my (%base,%beg_end,%end_beg,@rclinks,%rclink_h);
while (<BASE>) {
    chomp;
     my
($COUNTY,$ROUTE_TYPE,$ROUTE_NUM,$BEG_MEASURE,$END_MEASURE,$
SECTION_LENGTH,$DESCRIPTION,$DISTRICT,$MAINT_AREA,$POPULATI
ON,
     $INVENTORY_DATE,$DESIGNATED_WAY,$TRUCK_ROUTE,$TRAVEL_W
AY,$RURAL_URAN,$SPEED_LIMIT,$FAS_NUM,$TRUCK_ROUTE_ID,
     $CONGRESS_DIST,$STATE_ROUTE_SEQ,$ACCESS_CONTROL,$OPERA
TION,$TOTAL_LANES,$SPECIAL_CLASS,$DIV_HWY_SHLDR_WIDTH_LFT,
     $DIV_HWY_SHLDR_TYPE_LFT,$DIV_HWY_SURF_WIDTH,$DIV_HWY_S
URF_TYPE,$DIV_HWY_SHLDR_WIDTH_RT,$DIV_HWY_SHLDR_TYPE_RT,
     $DIV_HWY_MEDIAN_WIDTH,$DIV_HWY_MEDIAN_TYPE,$DIV_HWY_BA
RRIER_TYPE,$UDIV_HWY_SHLDR_WIDTH_LFT,$UDIV_HWY_SHLDR_TYPE_L
FT,
     $UDIV_HWY_SURFACE_WIDTH,$UDIV_HWY_SURFACE_TYPE,$UDIV_H
WY_SHLDR_WIDTH_RT,$UDIV_HWY_SHLDR_TYPE_RT,$AUX_LANE_WIDTH_L
FT,
     $AUX_LANE_TYPE_LFT,$AUX_LANE_WIDTH_RT,$AUX_LANE_TYPE_R
T,$MAINT_YEAR,$MAINT_TYPE,$IMPROVE_YEAR,$FUNC_CLASS,
     $TRAFFIC_COUNT_TYPE,$TRAFFIC_COUNT_YEAR,$RIGHT_OF_WAY,
$RW_TYPE,$TC_NUMBER,$MAINTENANCE_SUR_DES,$SIDEWALK_LEFT,
     $SIDEWALK_RIGHT,$IMPROVE_TYPE,$TRUCK_PERCENT,$TRUCK_PE
RCENT_TYPE,$SIGNAL,$AADT_OLD,$HPMS_ID,$PACES_RATING,$AADT,
     $INTERSECT_ROAD1,$INTERSECT_ROAD2,$S_FUNCLASS_ID,$DUAL
_MAINT_RATING,$ROAD_WIDTH,$DIVIDED,$OPEN_TO_TRAFFIC,
     $CITY_CODE,$T_LANES_LEFT,$T_LANES_RIGHT,$LAND_DOMAIN,$
RCLINK) = split /,/;
    #my @fields = split /,/;
```

```
     unless ($road_types eq 'all'){
          next unless $rc_string =~ /,$RCLINK,/;
          next unless $RCLINK =~ /^\d\d\d1/;
          next unless $DIV_HWY_BARRIER_TYPE == 0 ;
          next unless $DIV_HWY_MEDIAN_TYPE == 0 ;
          next unless $T_LANES_LEFT == 1 ;
          next unless $T_LANES_RIGHT == 1 ;
          next unless ($FUNC_CLASS == 2 || $FUNC_CLASS == 6
|| $FUNC_CLASS == 7);
     }
     #print "$RCLINK\n";
     my $skip = 1;
     foreach my $i (0..$filter_size){
          if ($RCLINK == $filters[$i][0]){
               $skip = 0;
               $skip = 1 unless (( ($filters[$i][1] >=
$BEG_MEASURE) && ($filters[$i][1] <= $END_MEASURE) )||
                              ( ($filters[$i][1] <=
$BEG_MEASURE) && ($filters[$i][2] >= $END_MEASURE) ) ||
                              ( ($filters[$i][2] >=
$BEG_MEASURE) && ($filters[$i][2] <= $END_MEASURE) )) ;#||
#if any of the ends of the RClink is within the CLRS
section
                              #( ($filters[$i][1] >
$BEG_MEASURE) && ($filters[$i][2] < $END_MEASURE) );  # if
the CLRS section is completely within the RCLINK
               print "$filters[$i][0]: ($filters[$i][1] <
$BEG_MEASURE) && ($filters[$i][2] > $END_MEASURE)\n" unless
$skip;
          }
     }
     next if $skip != 0;
    push @{$beg_end{$RCLINK}} , $BEG_MEASURE;
    push @{$end_beg{$RCLINK}} , $END_MEASURE;
    $base{$RCLINK}{$BEG_MEASURE} = $_;
    $rclink_h{$RCLINK} = 1;
}
my @rclinks = sort keys %rclink_h;


my @ext_head = (0..24);
```

```
close BASE;
open(ERR,">error.csv");

foreach my $file (@files){
     my
(%total,%fat,%inj,%microfilm,%iwf,%iwof,%fwoi,%nofi,%col2,%
col5,%col1,%col6);
    print "processing $file...\n";
    open(IN, "<$file");
    while (<IN>) {
        #my
($LOC_ACC_ID,$LOC_ACC_JULDT,$LOC_RCLINK_IDENTIFIER,$LOC_ACC
_MILELOG,$LOC_INTERROUTE_TYPE,
         #
$LOC_AADT_COUNT,$LOC_DIVHWYBARRIER_TYPE,$LOC_DIVHWYMEDIAN_T
YPE,$LOC_FUNCTIONALCLASS_TYPE,
          #
$LOC_LANESLEFT_COUNT,$LOC_LANESRIGHT_COUNT,$No_of_Injured,$
No_of_Fatalities,$Manner_of_Collision) = split /,/;

          my
($LOC_ACC_ID,$LOC_ACC_JULDT,$LOC_RCLINK_IDENTIFIER,$LOC_CIT
Y_IDENTIFIER,$LOC_COUNTY_IDENTIFIER,

     $LOC_ROUTE_TYPE,$LOC_ROUTE_IDENTIFIER,$LOC_ROUTE_SUFFI
X,$LOC_ACC_MILELOG,$LOC_ACC_MILELOGCUM,

     $LOC_INTERROUTE_TYPE,$LOC_INTERROUTE_IDENTIFIER,$LOC_I
NTERROUTE_SUFFIX,$LOC_ACCESSCONTROL_TYPE,

     $LOC_AADT_COUNT,$LOC_AUXLANELEFT_TYPE,$LOC_AUXLANERIGH
T_TYPE,$LOC_AUXLANELEFT_WIDTH,

     $LOC_AUXLANERIGHT_WIDTH,$LOC_DIVHWYBARRIER_TYPE,$LOC_D
IVHWYMEDIAN_TYPE,$LOC_FEDELIG_TYPE,

     $LOC_FUNCTIONALCLASS_TYPE,$LOC_RURALURBAN_TYPE,$LOC_SI
GNAL_TYPE,$LOC_SPEEDLIMIT_NUMBER,
```

```
     $LOC_LANESLEFT_COUNT,$LOC_LANESRIGHT_COUNT,$LOC_LOCATE
_DATE,$LOC_LOCATOR_IDENTIFIER,

     $LOC_X,$LOC_Y,$Microfilm,$Accident_Number,$NCIC_Number
,$Accident_County,$Accident_Date,

     $Day_of_Week,$Accident_Time,$No_of_Vehicles,$No_of_Inj
ured,$No_of_Fatalities,

     $No_of_Occupants,$Inside_City,$Rd_of_Occurence,$Inters
ect_With,$EMS_Notify,$EMS_Arrival,

     $HSP_Arrival,$Citations,$First_Harmful_Evnt,$Traffic_F
low,$Weather,$Surface_Condition,

     $Light_Condition,$Manner_of_Collision,$Location_of_Imp
act,$Road_Defects,$Other_Damage,

     $Hit_N_Run,$Flag_02,$Flag_03,$Flag_04,$Work_Zone,$Last
_Update,$Supplemental,
          $Supp_Microfilm,$ACC_Num_Suffix) = split /,/;

          if ($int_filter eq 'non_int'){
               if ( $LOC_INTERROUTE_TYPE ) {
                    next ;
               }
               if ( $LOC_INTERROUTE_IDENTIFIER ) {
                    next ;
               }
               if ( $LOC_INTERROUTE_SUFFIX ) {
                    next ;
               }

               if ( $LOC_INTERROUTE_TYPE ) {
                    next unless $LOC_INTERROUTE_TYPE =~
/null/i;
               }
               if ( $LOC_INTERROUTE_IDENTIFIER ) {
                    next unless $LOC_INTERROUTE_IDENTIFIER
=~ /null/i;
```

```
              }
              if ( $LOC_INTERROUTE_SUFFIX ) {
                   next unless $LOC_INTERROUTE_SUFFIX =~
/null/i;
              }
         }

         unless ($beg_end{$LOC_RCLINK_IDENTIFIER}){
           #print ERR $_;
           next;
        }
        my @mps = @{$beg_end{$LOC_RCLINK_IDENTIFIER}} ;
        my @mps2 = @{$end_beg{$LOC_RCLINK_IDENTIFIER}} ;
          @mps = sort {$a<=>$b} @mps;
          @mps2 = sort {$a<=>$b} @mps2;
          $" = "\n";
          #print "$.\t$LOC_RCLINK_IDENTIFIER\t@mps\n";
<STDIN>;
        my $size = scalar(@mps);
          next unless $size;
        my ($beg,$end);
        foreach my $i (0..$size-2){
            if (($LOC_ACC_MILELOG >= $mps[$i]) &&
($LOC_ACC_MILELOG < $mps2[$i])) {
                $beg = $mps[$i];
                $end = $mps2[$i];

                #print
"$i,$LOC_RCLINK_IDENTIFIER,$LOC_ACC_MILELOG,$beg,$end\n";
<STDIN>;
                    last;
            }

        }
          next unless $end;
        $total{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 ;
        $microfilm{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} .=
",$LOC_ACC_ID" ;
        $inj{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$No_of_Injured > 0;
```

```
        $fat{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$No_of_Fatalities > 0;
        $iwf{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured > 0 && $No_of_Fatalities > 0);
        $iwof{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured > 0 && $No_of_Fatalities == 0);
        $fwoi{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured == 0 && $No_of_Fatalities > 0);
        $nofi{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured == 0 && $No_of_Fatalities == 0);
        $col2{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 2;
        $col5{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 5;
        $col1{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 1;
        $col6{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 6;
    }

    close IN;
     die unless open(OUT,
">$file.20131203_2007RC.clrs.$int_filter.$road_types.csv");
     $" = ',';
     print OUT "$header,@ext_head\n";
     foreach my $rclink (@rclinks){
          my @beg = keys %{$base{$rclink}};
          foreach my $mp (@beg){
               print OUT
"$base{$rclink}{$mp},$total{$rclink}{$mp}{$file},$inj{$rcli
nk}{$mp}{$file},$fat{$rclink}{$mp}{$file},$iwf{$rclink}{$mp
}{$file},$iwof{$rclink}{$mp}{$file},$fwoi{$rclink}{$mp}{$fi
le},$nofi{$rclink}{$mp}{$file},$col2{$rclink}{$mp}{$file},$
col5{$rclink}{$mp}{$file},$col1{$rclink}{$mp}{$file},$col6{
$rclink}{$mp}{$file},$microfilm{$rclink}{$mp}{$file}\n";
          }
     }

     close OUT;
}
```

```
#my @rclinks = keys %base;
#@rclinks = sort @rclinks;
close ERR;

__END__

perl join_crash_to_segment_clrs.v2.pl
perl join_crash_to_segment_non_clrs.v2.pl
```

Joining Reference sites to Reference Roadways

```
use strict;


my $int_filter = 'non_int';
$int_filter = 'int';

my $road_types = 'all';

#LOC_ACC_ID,LOC_ACC_JULDT,LOC_RCLINK_IDENTIFIER,LOC_ACC_MIL
ELOG,LOC_INTERROUTE_TY
#PE,LOC_AADT_COUNT,LOC_DIVHWYBARRIER_TYPE,LOC_DIVHWYMEDIAN_
TYPE,LOC_FUNCTIONALCLA
#SS_TYPE,LOC_LANESLEFT_COUNT,LOC_LANESRIGHT_COUNT,No of
Injured,No of Fatalities,
#Manner of Collision

my $header =
'COUNTY,ROUTE_TYPE,ROUTE_NUM,BEG_MEASURE,END_MEASURE,SECTIO
N_LENGTH,DESCRIPTION,DISTRICT,MAINT_AREA,POPULATION,INVENTO
RY_DATE,DESIGNATED_WAY,TRUCK_ROUTE,TRAVEL_WAY,RURAL_URAN,SP
EED_LIMIT,FAS_NUM,TRUCK_ROUTE_ID,CONGRESS_DIST,STATE_ROUTE_
SEQ,ACCESS_CONTROL,OPERATION,TOTAL_LANES,SPECIAL_CLASS,DIV_
HWY_SHLDR_WIDTH_LFT,DIV_HWY_SHLDR_TYPE_LFT,DIV_HWY_SURF_WID
TH,DIV_HWY_SURF_TYPE,DIV_HWY_SHLDR_WIDTH_RT,DIV_HWY_SHLDR_T
YPE_RT,DIV_HWY_MEDIAN_WIDTH,DIV_HWY_MEDIAN_TYPE,DIV_HWY_BAR
RIER_TYPE,UDIV_HWY_SHLDR_WIDTH_LFT,UDIV_HWY_SHLDR_TYPE_LFT,
UDIV_HWY_SURFACE_WIDTH,UDIV_HWY_SURFACE_TYPE,UDIV_HWY_SHLDR
_WIDTH_RT,UDIV_HWY_SHLDR_TYPE_RT,AUX_LANE_WIDTH_LFT,AUX_LAN
E_TYPE_LFT,AUX_LANE_WIDTH_RT,AUX_LANE_TYPE_RT,MAINT_YEAR,MA
```

```
INT_TYPE,IMPROVE_YEAR,FUNC_CLASS,TRAFFIC_COUNT_TYPE,TRAFFIC
_COUNT_YEAR,RIGHT_OF_WAY,RW_TYPE,TC_NUMBER,MAINTENANCE_SUR_
DES,SIDEWALK_LEFT,SIDEWALK_RIGHT,IMPROVE_TYPE,TRUCK_PERCENT
,TRUCK_PERCENT_TYPE,SIGNAL,AADT_OLD,HPMS_ID,PACES_RATING,AA
DT,INTERSECT_ROAD1,INTERSECT_ROAD2,S_FUNCLASS_ID,DUAL_MAINT
_RATING,ROAD_WIDTH,DIVIDED,OPEN_TO_TRAFFIC,CITY_CODE,T_LANE
S_LEFT,T_LANES_RIGHT,LAND_DOMAIN,RCLINK,Total Crashes,
Injury Crashes, Fatal Crashes,Injury with Fatality,Injury
without Fatality,Fatality without Injury, No Fatality or
Injury,Headon,Sideswipe (opposite dir),Angle,Property Only
';


my $filterf = 'CLRS_Site_Extents.csv';
open FIL, "<$filterf";

my $i = 0;
my @filters;
my $rc_string = ',';
while(<FIL>){
     chomp;
     next unless /^\d/;
     my ($RCLINK,$BEG_MEASURE,$END_MEASURE) = split /,/;
     ($filters[$i][0], $filters[$i][1], $filters[$i][2]) =
($RCLINK,$BEG_MEASURE,$END_MEASURE);
     $i++;
     $rc_string .= "$RCLINK,";
}
my $filter_size = $i-1;
#

my $baselinef = "2012_BaseLine_Road_Data";
$baselinef = "RC_Data_2007";
my @files = glob ("2*crash*.txt");

open(BASE, "<$baselinef.txt");

my (%base,%beg_end,%end_beg,@rclinks,%rclink_h);
while (<BASE>) {
    chomp;
```

```
     my
($COUNTY,$ROUTE_TYPE,$ROUTE_NUM,$BEG_MEASURE,$END_MEASURE,$
SECTION_LENGTH,$DESCRIPTION,$DISTRICT,$MAINT_AREA,$POPULATI
ON,
     $INVENTORY_DATE,$DESIGNATED_WAY,$TRUCK_ROUTE,$TRAVEL_W
AY,$RURAL_URAN,$SPEED_LIMIT,$FAS_NUM,$TRUCK_ROUTE_ID,
     $CONGRESS_DIST,$STATE_ROUTE_SEQ,$ACCESS_CONTROL,$OPERA
TION,$TOTAL_LANES,$SPECIAL_CLASS,$DIV_HWY_SHLDR_WIDTH_LFT,
     $DIV_HWY_SHLDR_TYPE_LFT,$DIV_HWY_SURF_WIDTH,$DIV_HWY_S
URF_TYPE,$DIV_HWY_SHLDR_WIDTH_RT,$DIV_HWY_SHLDR_TYPE_RT,
     $DIV_HWY_MEDIAN_WIDTH,$DIV_HWY_MEDIAN_TYPE,$DIV_HWY_BA
RRIER_TYPE,$UDIV_HWY_SHLDR_WIDTH_LFT,$UDIV_HWY_SHLDR_TYPE_L
FT,
     $UDIV_HWY_SURFACE_WIDTH,$UDIV_HWY_SURFACE_TYPE,$UDIV_H
WY_SHLDR_WIDTH_RT,$UDIV_HWY_SHLDR_TYPE_RT,$AUX_LANE_WIDTH_L
FT,
     $AUX_LANE_TYPE_LFT,$AUX_LANE_WIDTH_RT,$AUX_LANE_TYPE_R
T,$MAINT_YEAR,$MAINT_TYPE,$IMPROVE_YEAR,$FUNC_CLASS,
     $TRAFFIC_COUNT_TYPE,$TRAFFIC_COUNT_YEAR,$RIGHT_OF_WAY,
$RW_TYPE,$TC_NUMBER,$MAINTENANCE_SUR_DES,$SIDEWALK_LEFT,
     $SIDEWALK_RIGHT,$IMPROVE_TYPE,$TRUCK_PERCENT,$TRUCK_PE
RCENT_TYPE,$SIGNAL,$AADT_OLD,$HPMS_ID,$PACES_RATING,$AADT,
     $INTERSECT_ROAD1,$INTERSECT_ROAD2,$S_FUNCLASS_ID,$DUAL
_MAINT_RATING,$ROAD_WIDTH,$DIVIDED,$OPEN_TO_TRAFFIC,
     $CITY_CODE,$T_LANES_LEFT,$T_LANES_RIGHT,$LAND_DOMAIN,$
RCLINK) = split /,/;
     #
     #TWTL control station criteria
     #
     #next unless $ROUTE_TYPE == 1;
     unless ($road_types eq 'all'){
          next unless $RCLINK =~ /^\d\d\d1/;
          next unless $DIV_HWY_BARRIER_TYPE == 0 ;
          next unless $DIV_HWY_MEDIAN_TYPE == 0 ;
          next unless $T_LANES_LEFT == 1 ;
          next unless $T_LANES_RIGHT == 1 ;
          next unless ($FUNC_CLASS == 2 || $FUNC_CLASS == 6
|| $FUNC_CLASS == 7);
     }
    #my @fields = split /,/;
     if ($rc_string =~ /,$RCLINK,/){
```

```
          my $skip ;

          foreach my $i (0..$filter_size){
               if ($RCLINK == $filters[$i][0]){
                    #$skip =0;
                    $skip = 1 if ( ($filters[$i][1] >= 
$BEG_MEASURE) && ($filters[$i][1] <= $END_MEASURE) )||
                                   ( ($filters[$i][1] <= 
$BEG_MEASURE) && ($filters[$i][2] >= $END_MEASURE) ) ||
                                   ( ($filters[$i][2] >= 
$BEG_MEASURE) && ($filters[$i][2] <= $END_MEASURE) ) ;# ||
#if any of the ends of the RClink is within the CLRS 
section
                                   #( ($filters[$i][1] > 
$BEG_MEASURE) && ($filters[$i][2] < $END_MEASURE) );  # if 
the CLRS section is completely within the RCLINK
               }
          }
          next if $skip;
     }
    push @{$beg_end{$RCLINK}} , $BEG_MEASURE;
    push @{$end_beg{$RCLINK}} , $END_MEASURE;
    $base{$RCLINK}{$BEG_MEASURE} = $_;
    $rclink_h{$RCLINK} = 1;
}
my @rclinks = sort keys %rclink_h;

my @ext_head = (0..24);

close BASE;
open(ERR,">error.csv");

foreach my $file (@files){
     my 
(%total,%fat,%inj,%microfilm,%iwf,%iwof,%fwoi,%nofi,%col2,%
col5,%col1,%col6);
    print "processing $file...\n";
    open(IN, "<$file");
    while (<IN>) {
```

```
        #my
($LOC_ACC_ID,$LOC_ACC_JULDT,$LOC_RCLINK_IDENTIFIER,$LOC_ACC
_MILELOG,$LOC_INTERROUTE_TYPE,
         #
$LOC_AADT_COUNT,$LOC_DIVHWYBARRIER_TYPE,$LOC_DIVHWYMEDIAN_T
YPE,$LOC_FUNCTIONALCLASS_TYPE,
          #
$LOC_LANESLEFT_COUNT,$LOC_LANESRIGHT_COUNT,$No_of_Injured,$
No_of_Fatalities,$Manner_of_Collision) = split /,/;

          my
($LOC_ACC_ID,$LOC_ACC_JULDT,$LOC_RCLINK_IDENTIFIER,$LOC_CIT
Y_IDENTIFIER,$LOC_COUNTY_IDENTIFIER,

     $LOC_ROUTE_TYPE,$LOC_ROUTE_IDENTIFIER,$LOC_ROUTE_SUFFI
X,$LOC_ACC_MILELOG,$LOC_ACC_MILELOGCUM,

     $LOC_INTERROUTE_TYPE,$LOC_INTERROUTE_IDENTIFIER,$LOC_I
NTERROUTE_SUFFIX,$LOC_ACCESSCONTROL_TYPE,

     $LOC_AADT_COUNT,$LOC_AUXLANELEFT_TYPE,$LOC_AUXLANERIGH
T_TYPE,$LOC_AUXLANELEFT_WIDTH,

     $LOC_AUXLANERIGHT_WIDTH,$LOC_DIVHWYBARRIER_TYPE,$LOC_D
IVHWYMEDIAN_TYPE,$LOC_FEDELIG_TYPE,

     $LOC_FUNCTIONALCLASS_TYPE,$LOC_RURALURBAN_TYPE,$LOC_SI
GNAL_TYPE,$LOC_SPEEDLIMIT_NUMBER,

     $LOC_LANESLEFT_COUNT,$LOC_LANESRIGHT_COUNT,$LOC_LOCATE
_DATE,$LOC_LOCATOR_IDENTIFIER,

     $LOC_X,$LOC_Y,$Microfilm,$Accident_Number,$NCIC_Number
,$Accident_County,$Accident_Date,

     $Day_of_Week,$Accident_Time,$No_of_Vehicles,$No_of_Inj
ured,$No_of_Fatalities,

     $No_of_Occupants,$Inside_City,$Rd_of_Occurence,$Inters
ect_With,$EMS_Notify,$EMS_Arrival,
```

```
     $HSP_Arrival,$Citations,$First_Harmful_Evnt,$Traffic_F
low,$Weather,$Surface_Condition,

     $Light_Condition,$Manner_of_Collision,$Location_of_Imp
act,$Road_Defects,$Other_Damage,

     $Hit_N_Run,$Flag_02,$Flag_03,$Flag_04,$Work_Zone,$Last
_Update,$Supplemental,
          $Supp_Microfilm,$ACC_Num_Suffix) = split /,/;

          if ($int_filter eq 'non_int'){
               if ( $LOC_INTERROUTE_TYPE ) {
                    next ;
               }
               if ( $LOC_INTERROUTE_IDENTIFIER ) {
                    next ;
               }
               if ( $LOC_INTERROUTE_SUFFIX ) {
                    next ;
               }

               if ( $LOC_INTERROUTE_TYPE ) {
                    next unless $LOC_INTERROUTE_TYPE =~
/null/i;
               }
               if ( $LOC_INTERROUTE_IDENTIFIER ) {
                    next unless $LOC_INTERROUTE_IDENTIFIER
=~ /null/i;
               }
               if ( $LOC_INTERROUTE_SUFFIX ) {
                    next unless $LOC_INTERROUTE_SUFFIX =~
/null/i;
               }
          }
          unless ($beg_end{$LOC_RCLINK_IDENTIFIER}){
            #print ERR $_;
            next;
        }
        my @mps = @{$beg_end{$LOC_RCLINK_IDENTIFIER}} ;
        my @mps2 = @{$end_beg{$LOC_RCLINK_IDENTIFIER}} ;
```

```
          @mps = sort {$a<=>$b} @mps;
          @mps2 = sort {$a<=>$b} @mps2;
          $" = "\n";
          print "$.\t$LOC_RCLINK_IDENTIFIER\t@mps\n" if
$LOC_RCLINK_IDENTIFIER == 1391005300;
        my $size = scalar(@mps);
          next unless $size;
        my ($beg,$end);
        foreach my $i (0..($size-1)){
               next unless $mps[$i+1];
               die
"LOC_RCLINK_IDENTIFIER,$mps[$i],$mps[$i+1],@mps" if
$mps[$i] > $mps[$i+1];
            if (($LOC_ACC_MILELOG >= $mps[$i]) &&
($LOC_ACC_MILELOG < $mps2[$i])) {
                $beg = $mps[$i];
                $end = $mps2[$i];
                last;
            }

        }
          next unless $end;
          print "$beg,$LOC_ACC_MILELOG,$end\n"  if
$LOC_RCLINK_IDENTIFIER == 1391005300;
        $total{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 ;
        $microfilm{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} .=
",$LOC_ACC_ID" ;
        $inj{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$No_of_Injured > 0;
        $fat{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$No_of_Fatalities > 0;
        $iwf{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured > 0 && $No_of_Fatalities > 0);
        $iwof{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured > 0 && $No_of_Fatalities == 0);
        $fwoi{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured == 0 && $No_of_Fatalities > 0);
        $nofi{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
($No_of_Injured == 0 && $No_of_Fatalities == 0);
        $col2{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 2;
```

```
        $col5{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 5;
        $col1{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 1;
        $col6{$LOC_RCLINK_IDENTIFIER}{$beg}{$file} += 1 if
$Manner_of_Collision == 6;
    }

    close IN;
     die unless open(OUT,
">$file.20131203_2007RC.non_clrs.$int_filter.$road_types.cs
v");
     $" = ',';
     print OUT "$header,@ext_head\n";
     foreach my $rclink (@rclinks){
          my @beg = keys %{$base{$rclink}};
          foreach my $mp (@beg){
               print OUT
"$base{$rclink}{$mp},$total{$rclink}{$mp}{$file},$inj{$rcli
nk}{$mp}{$file},$fat{$rclink}{$mp}{$file},$iwf{$rclink}{$mp
}{$file},$iwof{$rclink}{$mp}{$file},$fwoi{$rclink}{$mp}{$fi
le},$nofi{$rclink}{$mp}{$file},$col2{$rclink}{$mp}{$file},$
col5{$rclink}{$mp}{$file},$col1{$rclink}{$mp}{$file},$col6{
$rclink}{$mp}{$file},$microfilm{$rclink}{$mp}{$file}\n";
          }
     }

     close OUT;
}

#my @rclinks = keys %base;
#@rclinks = sort @rclinks;
close ERR;

__END__

perl join_crash_to_segment_clrs.2007.pl
perl join_crash_to_segment_non_clrs.2007.pl
```

REFERENCES

[1] Alluri, P. (2008). “Assessment of Potential Site Selection Methods for Use in Prioritizing Safety Improvements on Georgia Roadways.” M.S. thesis, Clemson University, Clemson, SC.

[2] Bahar, G. and Parkhill, M. (2005). “Synthesis of Practices for the Implementation of Centreline Rumble Strips.” *Traffic Operations and Management Initiatives Session*, Transportation Association of Canada, Calgary, AB.

[3] “Before-and-After Study Technical Brief.” (2009*). Institute of Transportation Engineers.*

[4] Briese, M. (2006). “Safety Effects of Centerline Rumble Strips in Minnesota.” *Minnesota Department of Transportation*, St. Paul, MN, Report No. MN/RC – 2008-44.

[5] Carlson, P. J. and Miles, J. D. (2003). “Effectiveness of Rumble Strips on Texas Highways: First Year Report.” *Texas Department of Transportation*, Austin, TX, Report No. FHWA/TX-05/0-4472-1.

[6] “Centerline Rumble Strips, the Delaware Experience.” (2003). *Delaware Department of Transportation*, Dover, DE.

[7] Corkle, J., Marti, M., and Montebello, D. (2001). “Synthesis on the Effectiveness of Rumble Strips.” *Minnesota Department of Transportation*, St. Paul, MN, Report No. MN/RC – 2002-07.

[8] “Design Manual.” (2012). *Washington State Department of Transportation*, Olympia, WA.

[9] “Engineering Concerns.” (1999). *Federal Highway Administration*, < http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/concerns_eng.cfm> (Mar. 25, 2013)

[10] “Evaluation of Rumble Strips.” (2006). *Civil Engineering Research Institute for Cold Region (CERI)*, Hokkaido, Japan.

[11] Garder, P. and Alexander, J. (1995). “Continued Research on Continuous Rumble Strips.” *Maine Department of Transportation*, Augusta, ME, Report 94-4.

[12] "Georgia Uniform Vehicle Accident Report. Instruction Guide, Version 2.0." (2003). *Georgia Department of Transportation*, Atlanta, GA.

[13] (2013). "Google Earth." <http://maps.google.com> (Nov. 15, 2013).

[14] (2013). "Google Maps." <http://maps.google.com> (Nov. 15, 2013).

[15] (2013). "Google Street View." <http://maps.google.com> (Nov. 15, 2013).

[16] Gross, F., Persaud, B., and Lyon, C. (2010). "A Guide to Developing Quality Crash Modification Factors." *U.S. Department of Transportation*, Washington D.C., Report No. FHWA-SA-10-032.

[17] Harwood, D.W. (1993). "NCHRP Synthesis 191: Use of Rumble Strips to Enhance Safety." *Transportation Research Board, National Research Council*, Washington, D.C.

[18] Hauer, E. (1997). "Observational Before-After Studies in Road Safety." Elsevier Science Inc., Tarrytown, NY.

[19] Hauer, E., et al. (2002). "Estimating Safety by the Empirical Bayes Method: A Tutorial. Transportation Research Record 1784." *Transportation Research Board, National Research Council*, Washington, D.C., 126-131.

[20] "Highway Safety Manual." (2010). *American Association of State Highway and Transportation Officials*, Washington, D.C.

[21] Karkle, D. E., Rys, M. J., and Russell, E. R. (2011). "State-of-the-Art: Centerline Rumble Strips Usage in the United States." *Journal of the Transportation Research Forum*, 50(1), 101-117.

[22] Karkle, D. E., Rys, M. J., and Russell, E. R. (2013). "Safety Effectiveness of Centerline Rumble Strips in Kansas." *Journal of Transportation Safety & Security*, 5, 1-26.

[23] Kirk, A. (2008). "Evaluation of the Effectiveness of Pavement Rumble Strips." *Kentucky Transportation Cabinet*, Frankfort, KY, Report No. KTC-08-04 / SPR319-06-1F.

[24] "KML Tools." (2013). < http://kmltools.nobletech.com/> (Jan. 9, 2013).

[25] Kuo, P. F. and Lord, D. "Accounting for Site-Selection Bias in Before-After Studies for Continuous Distributions: Characteristics and Application Using Speed Data." *Texas A&M University*, College Station, TX.

[26] Lipscomb, D. M. (1995). "Auditory Perceptual Factors Influencing the Ability of Train Horns." *Third International Symposium on Railroad-Highway Grade Crossing Research and Safety*, Tennessee Transportation Center, Knoxville, TN.

[27] Lord, D., et al. (2011). "Analysis of Roadway Departure Crashes on Two-Lane Rural Roads in Texas." *Texas Department of Transportation*, Austin, TX, Report No. FHWA/TX-11/0-6031-1.

[28] Miller, K. W. (2008). "Effects of Center-Line Rumble Strips on Non-Conventional Vehicles." *Minnesota Department of Transportation*, St. Paul, MN, Report No. MN/RC 2008-07.

[29] Morena, D.A. (2003). "Rumbling Toward Safety." *Public Roads*, 67(2), 28–33.

[30] Neuman, T.R., et al. (2003). "NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Vol. 4: A Guide for Addressing Head-On Collisions." *Transportation Research Board, National Research Council*, Washington, D.C.

[31] Noyce, D. A. and Elango, V.V. (2003). "Safety Evaluation of Centerline Rumble Strips." *Massachusetts Highway Department*, Boston, MA.

[32] Ogden, K. W. (1996). "Safer Roads: A Guide to Road Safety Engineering." Ashgate Publishing Company, Brookfield, VT.

[33] Olson, D. et al. (2011). "Performance Analysis of Centerline Rumble Strips in Washington State." *Washington State Department of Transportation*, Olympia, WA, Report No. WA-RD 768.1.

[34] Outcalt, W. (2001). "Centerline Rumble Strips." *Colorado Department of Transportation*, Denver, CO, Report No. CDOT-DTD-R-2001-8, Interim Report.

[35] Ozbay, K. et al. (2009). "Safety Comparison of Roadway Design Elements on Urban Collectors with Access." *New Jersey Department of Transportation*, *Federal Highway Administration*, Trenton, NJ, Report No. FHWA-NJ-2009-008.

[36] Persaud, B., Retting, R., and Lyon, C. (2003). "Crash Reducing Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads." *Insurance Institute for Highway Safety*, Arlington, VA.

[37] Richards, S. J. N. and Saito, M. (2007). "State-of-the-Practice and Issues Surrounding Centerline Rumble Strips." *WIT Transactions on the Built Environment*, 94, 36-45.

[38] "Rumble Strip Types." *Federal Highway Administration*, <http://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/rumble_types/> (Jan. 15, 2013).

[39] Russell, E. R. and Rys, M. J. (2005). "NCHRP Synthesis 339: Centerline Rumble Strips." *Transportation Research Board, National Research Council*, Washington D.C.

[40] Russell, E. R. and Rys, M. J. (2006). "Reducing Crossover Accidents on Kansas Highways Using Milled Centerline Rumble Strips." *Kansas Department of Transportation*, Topeka, Kansas, Report No. K-TRAN: KSU-00-4.

[41] Russell, E. R., Rys, M. J., and Brin, T. S. (2003). "US Experience with Centerline Rumble Strips on Two-Lane Roads: Pattern Research and North American Usage." *Kansas State University*, Manhattan, KS.

[42] Rhys, M. J., Karkle, D. E. and Russell, E. R. (2012). "Study of KDOT Policy on Lane and Shoulder Minimum Width for Application of Centerline Rumble Strips." *Kansas Department of Transportation*, Topeka, KS, Report No. K-TRAN: KSU-10-7.

[43] (2005). "Safety Action Plan." *Georgia Department of Transportation*, Atlanta, GA.

[44] Srinivasan, R. and Carter, D. (2011). "Development of Safety Performance Functions for North Carolina." *North Carolina Department of Transportation*, Raleigh, NC, Report No. FHWA/NC/2010-09.

[45] Suzman, J. (1999). "Rumble Strips: A Wake-Up Call for Drowsy Drivers." *IMSA Journal*, 37(6).

[46] (2011). "Technical Advisory: Shoulder Rumble Strips." *Federal Highway Administration*, T 5040.39, Revision 1.

[47] (2011). “Technical Advisory: Centerline Rumble Strips.” *Federal Highway Administration*, T 5040.40, Revision 1.

[48] (2012). “Traffic Noise Generated by Rumble Strips.” *Caltrans Division of Research and Innovation*, Sacramento, CA.

[49] (2010). “Traffic Safety Facts.” *U.S. Department of Transportation*. Washington, D.C., Report No. HS-811-395.

[50] (2002). “Traffic Safety Facts 2001: Rural/Urban Comparison.” *U.S. Department of Transportation*. Washington, D.C., Report No. HS-809-524.

[51] (2013). “Transportation Project Information (TransPI).” *Georgia Technology Authority*. < http://gta.georgia.gov/annualreport/transportation-project-information-transpi> (Nov. 9, 2013).

[52] “Transportation Project Information (TransPI).” *Georgia Department of Transportation*. <http://www.dot.ga.gov/projects/transpi/Pages/ProjectSelection.aspx> (Nov. 9, 2013).

[53] Torbic, D. J., et al. (2009). “NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips.” *Transportation Research Board*, *National Research Council*, Washington D.C.

[54] Watson, M. et al. (2008). “Long Term Maintenance Effects on HMA Pavements Caused by Rumble Strips and Available Preventative Treatment Methods.” *Minnesota Department of Transportation*, St. Paul, MN, Report No. MN/RC 2008-50.